THE MICROSCOPE.

BY DR LARDNER.


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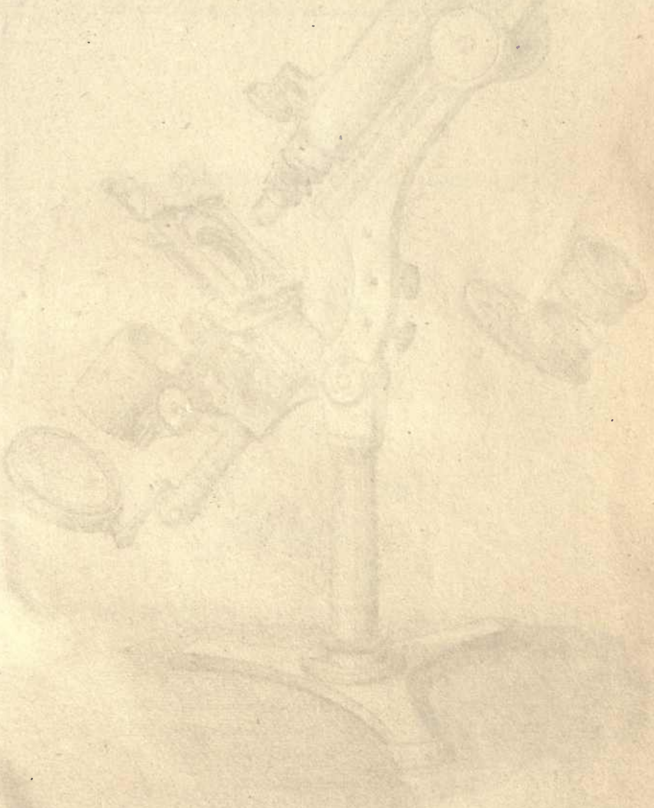

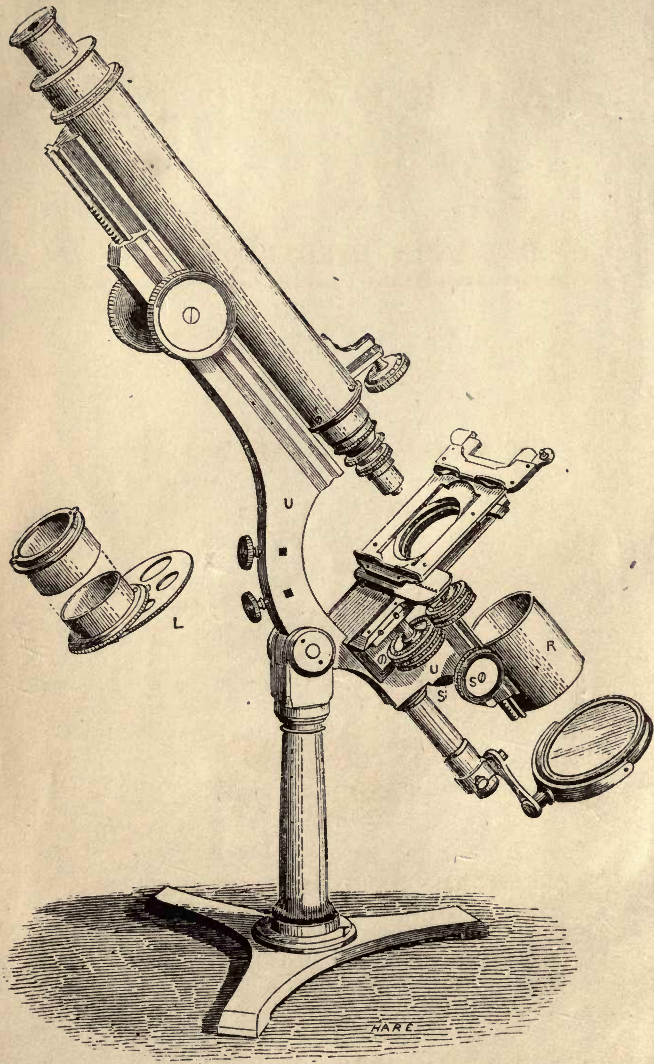
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THE

MICROSCOPE.

BY

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FROM

"THE MUSEUM OF SCIENCE AND ART."

WITH ONE HUNDRED AND FORTY SEVEN ENGRAVINGS.

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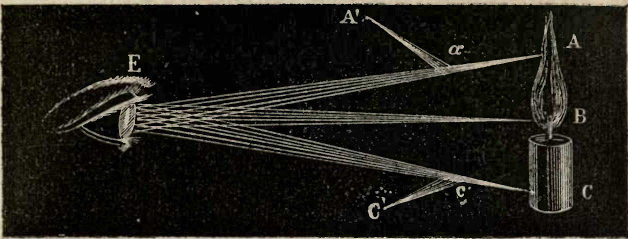


Fig. 1.

OPTICAL IMAGES.

CHAPTER I.

1. Great importance of the subject in relation to all the effects of vision.—2. Explanation of how an object is seen with the naked eye.—3. Images produced by plane reflectors.—4. How rays are reflected from such surfaces.—5. Experimental verifications of this.—6. Image of a point in a plane reflecting surface.—7. Image of an object in the same. — 8. Real and imaginary images. — 9. Images produced by spherical reflectors.—10. By a concave reflector.—11. Experimental verification.—12. Variation of position, and magnitude of image.—13. Images in convex reflectors.—14. Images produced by transparent bodies.—15. Refraction.—16. Cases in which light will not enter a transparent body. — 17. Reflection of objects in water.—18. The fallacy of the fable of "the Dog and the Shadow."—19. Objects seen at the bottom of a transparent body.—20. Case of water and glass.—21. Broken appearance of a rod immersed in water.—22. Cases in which rays cannot emerge from a transparent body.—23. Experimental verification.—24. Reflection by a rectangular Prism.—25. Images produced by lenses.—26. Six kinds of lenses.—27. The axis of a lens.—28. Example of each kind of lens.—29. Optical image produced by a convex lens.—30. Relative position of the object and image.

1. The images of visible objects produced by reflection from smooth or polished surfaces, natural and artificial, and by looking through transparent media, bounded by surfaces having certain curved shapes, play a part so important in the effects of vision, that it must be regarded as highly interesting to explain the optical principles upon which the production of such images depends, so far at least as may be necessary to render intelligible

the natural appearances and effects which are familiar to every eye, and innumerable contrivances, from which we derive essential benefit, either in repairing defects of vision, or extending the range of that sense to objects removed beyond its natural limits, either because of their minuteness or remoteness, or in fine in producing phenomena affording at once amusement and instruction.

The landscape seen inverted in the tranquil surface of the river or lake; the ship seen reproduced in like manner in the face of a calm sea; our persons, and the objects which surround us, seen in a looking-glass; the clear vision conferred on weak eyes by one sort of spectacle-glass, and the distinct vision conferred on strong but short-sighted eyes, by another; the apparent enlargement produced by magnifying glasses; the clear view of the scene and its personages afforded by the opera-glass; in fine, the marvellous world of minuteness opened to our view by the microscope, and the sublime spectacle of the remote regions of space, teeming with countless systems of suns and circumvolving worlds, displayed before us by the telescope, are a few, and only a few, of the innumerable things of wonder and interest, to comprehend which is impossible without some knowledge of the manner in which optical images are produced.

As we shall, from time to time, present all these interesting subjects in the pages of the "Museum," we propose now, as an indispensable preliminary, to explain with as much brevity as may be compatible with clearness, the principles upon which the natural and artificial production of optical images depends.

2. It is, in the first place, and above all things, necessary to understand the manner in which the eye obtains the perception of any visible object, because if we can show that precisely the same means are called into operation in the case of an optical image, we shall understand how the latter produces the same sensible impression as the object itself.

To comprehend this, then, it is necessary to consider that each point of a visible object is a focus from which rays of light diverge exactly as if the point were luminous. Some of these divergent rays are received by the eye, and enter it through the circular hole called the pupil,* and there produce a perception of the point of the object from which they have radiated. Since *each* point of the object is thus a distinct focus, or centre of radiation, a perception of each point, and therefore of the whole object, is thus produced.

* See Tract on THE EYE, vol. v., pp. 54, 55.

This will be rendered more clear by reference to fig. 1. Let A, B, C, be a candle, for example, placed before the eye, E. Rays diverge from the top, A, of the flame, and enter the pupil. A cone of these rays, whose point is at A, and whose base is the pupil, enter the eye, and being collected on the retina, produce a perception of the point A.* And other cones, or PENCILS, as they are called, proceeding from the points B and C, and, in general, from all the points of the candle, radiate to the pupil in like manner, and severally produce perceptions, and so a perception of the candle is produced.

Now, if A, B, C, instead of being a real candle, were merely the optical image of a candle, the same perception of its presence would be produced, provided the same rays radiated in like manner from each point to the eye, and the observer would see it exactly as he would see the object itself, were it in the same position.

But it is not even necessary to the production of the perception that either the object or its image should be present, if the rays, no matter where they may have originated, or what route they may have followed, only enter the eye in the same lines of direction which they would have, had they come directly from the object. Thus, for example, if the pencils, instead of coming from A and C, had come from a similar point at A′ and C′ towards *a* and *c*, and had there by any optical agency been turned into the directions which they would have had, if they had come from A and C to the pupil, the perception produced by them would be exactly the same.

In fine, the perceptions produced depend on the directions which the rays have in entering the pupil, and are altogether independent of the route they may have followed before arriving there.

It will be most necessary that this fact be impressed on the memory, since the whole theory of vision, especially where optical agents are used, depends more or less upon it.

3. IMAGES PRODUCED BY PLANE REFLECTORS.

The most simple case of the production of optical images, and that of most frequent occurrence, is when they are produced by reflection from plane surfaces; as when a landscape and the firmament are seen reflected in the surface of water, or when objects are seen in a looking-glass.

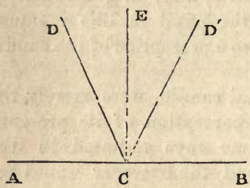
To explain this very familiar phenomenon, it is necessary first

* See Tract on THE EYE, vol. v., pp. 54, 55.

to explain the manner in which rays of light are reflected when these fall on a plane surface.

4. The rays are reflected in this case exactly as an elastic ball is repelled when it encounters a hard and flat surface. Let C, fig. 2, be a point upon a reflecting surface A C, upon which a ray of light D C is incident. Draw the line C E perpendicular to the reflecting surface at C; the angle formed by this perpendicular, and the incident ray D C, is called the *angle of incidence.*

Fig. 2.



From the point C, draw a line C D′ in the plane of the angle of incidence D C E, and forming with the perpendicular C E an angle E C D′, equal to the angle of incidence, but lying on the other side of the perpendicular. This line C D′ will be the direction in which the ray will be reflected from the point C. The angle D′ C E is called the *angle of reflection.*

The plane of the angles of incidence and reflection which passes through the two rays C D and C D′, and through the perpendicular C E, and which is therefore at right angles to the reflecting surface, is called the *plane of reflection.*

This law of reflection from perfectly polished surfaces, which is of great importance in the theory of light and vision, is expressed as follows:—

When light is reflected from a perfectly polished surface, the angle of incidence is equal to the angle of reflection, in the same plane with it, and on the opposite side of the perpendicular to the reflecting surface.

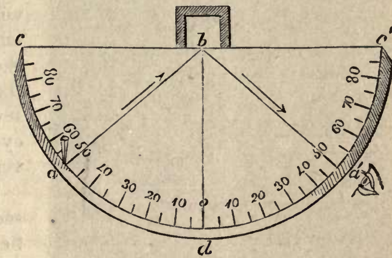
From this law it follows, that if a ray of light fall perpendicularly on a reflecting surface, it will be reflected back perpendicularly, and will return upon its path; for in this case, the angle of incidence and the angle of reflection being both nothing, the reflected and incident rays must both coincide with the perpendicular. If the point C be upon a concave or convex surface, the same conditions will prevail; the line C E, which is perpendicular to the surface, being then what is called in geometry, the normal.

5. This law of reflection may be experimentally verified as follows:—

Let *c d c′*, fig. 3, be a graduated semicircle, placed with its diameter *c c′* horizontal. Let a plumb-line *b d* be suspended from its centre *b*, and let the graduated arch be so adjusted that the plumb-line shall intersect it at the zero point of the division, the

divisions being numbered from that point in each direction towards *c* and *c′*. Let a small reflector (a piece of looking-glass will answer the purpose) be placed upon the horizontal diameter at the centre with its reflecting surface downwards, and let any convenient and well-defined object be placed upon the graduated arch at any point, such as *a*, between *d* and *c*. Now, if the point *a′* be taken upon the arch *d c* at a distance *d a′* from *d* equal to *d a*, the eye placed at *a′* and directed

Fig. 3.



to *b* will perceive the object *a* as if it were placed in the direction *a′ b*. It follows, therefore, that the light issuing from the point of the object *a* in the direction *a b*, is reflected to the eye in the direction *b a′*. In this case, the angle *a b d* is the angle of incidence, and the angle *d b a′* is the angle of reflection; and, whatever position may be given to the object *a*, it will be found that, in order to see it in the reflector *b*, the eye must be placed upon the arch *d c′*, at a distance from *d* equal to the distance at which the object is placed from *d* upon the arch *d c*.

The same principle may also be experimentally illustrated as follows:—

If a ray of sun-light admitted into a dark room through a small hole in a window-shutter strike upon the surface of a mirror, it will be reflected from it, and both the incident and reflected rays will be rendered visible by the particles of dust floating in the room. By comparing the direction of these two visible rays with the direction of the plane of the mirror and the position of the point of incidence, it will be found that the law of reflection which has been announced is verified.

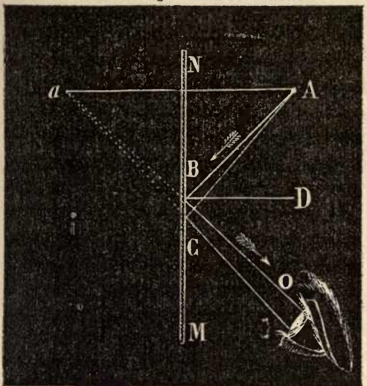
6. This being premised, it will be easy to comprehend the manner in which images are produced by reflection from plane surfaces.

Let A, fig. 4, be any point of a visible object placed before a plane reflector, M N. Let A B and A C be two rays diverging from it, and reflected from B and C to an eye at O. After reflection, they will proceed as if they had issued from a point, *a*, as far behind the reflector as the point, A, is before it; that is to say, the distance A N will be equal to *a* N.

It is easy to verify this, by taking into account the law of

reflection already explained. If B D be at right angles to M N, the angle, D B O, will be equal to B *a* N, and also to D B A, and consequently to B A N, from whence it follows that B A is equal to B *a*, and A N to *a* N: and since the same will be true of all rays which issue from A towards the reflector, it follows that, after reflection, all such rays will enter the eye, O, as if they had diverged from *a*.

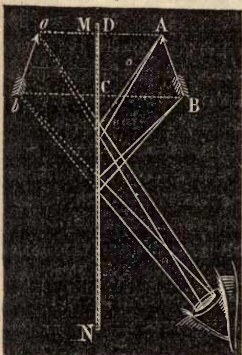
Fig. 4.



The eye O will therefore see the point A in the reflector as if it were at *a*.

7. But since the same will be true of each point in an object, A B (fig. 5), placed before the reflector, it follows that the rays which proceed from the several points of the object will, after reflection, enter the eye, as if they came from corresponding points of a similar object *a b*, placed just as far *behind* the reflector as the object itself A B is *before* it.

Fig. 5.



It is evident that in this case the image *a b* is not only similar to the object but precisely equal to it. Its position relatively to the reflector is similar to that of the object, but in an absolute sense it is different, as will be evident from observing that while the arrow A B points to the left, its image *a b* points to the right.

8. It will be perceived, that the reflected rays by which the perception of the image is produced, do not actually form the image. They enter the eye as if they actually came from the several points of such an image as the eye sees, but they do not come from such points. In such cases, where the image is perceived, but not actually produced, it is called a *virtual* or *imaginary image*. When the rays by which the image is perceived do actually diverge from the points of the image, the image is said to be REAL.

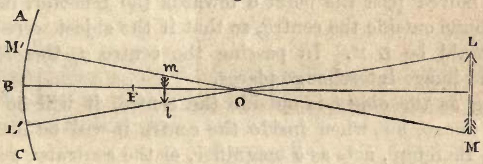
Since, in all the cases of reflection from plane mirrors, the rays diverge as if they had issued from points behind the mirror, the images are always virtual or imaginary.

9. IMAGES PRODUCED BY SPHERICAL REFLECTORS.

Curved reflecting surfaces may have various forms, but those which are most important are spherical; that is, such as consist of a part of the surface of a globe of greater or less diameter. A concave spherical reflector is a part of the surface of a globe seen from the inside, and a convex, seen from the outside.

10. Let A C (fig. 6) be the section of a concave reflector, whose centre is O. The line O B through the middle of the reflector

Fig. 6.



and the centre, O, is called its axis. Let F be the middle point of the radius O B.

If an object be placed before the reflector at any place, such as L M, beyond its centre O, an image of this object *m l*, will be found at a certain point between F and O. The pencils of rays which radiate from each point of the object, after encountering the surface of the reflector, will be reflected, converging to the corresponding points of the image. Thus the rays which proceed from L will be reflected, converging to *l*, and those which proceed from M will be reflected, converging to *m*.

The image *m l* will therefore be inverted with relation to the object, the top of the one corresponding to the bottom of the other, the right to the left, and *vice versâ*.

It is evident also, that the linear dimensions of the image will bear to those of the object the exact proportion of their respective distances *m* O and M O from the centre of the reflector.

11. The production of such an image can be easily verified experimentally. Let the object L M be a candle, and let a small piece of card be held between O and F at right angles to O B. An image of the candle will be seen upon the side of the card presented to the reflector. The image will at first be nebulous and indistinct, but by moving the card alternately to and from the

centre O, a position will be found at which the image will be distinct. The card in this case should be so small as not to intercept too much of the light radiated from the candle to the mirror.

12. If the candle be now supposed to be gradually removed to greater and greater distances from the reflector, the image will approach nearer and nearer to the middle point F of the radius O B, and when its distance attains a certain limit, the image will be formed at F. However much the distance may be further augmented, the image will remain stationary at F.

This point F being therefore the place at which the images of all very distant objects are formed, is called the PRINCIPAL FOCUS of the reflector.

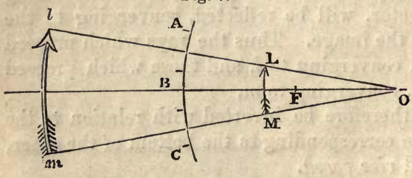
If the object L M be supposed to be moved continually towards the centre O, its image *l m* will also move towards O. When the object is moved past the point O towards the reflector, its image will be found outside the centre, so that if the object were *m l* the image would be L M. In passing the centre O, therefore, the object and image interchange places.

So long as the object is outside the centre, it will be greater than its image, but when inside the centre it will be less. The reflector, therefore, acts as a magnifier, or the contrary, according as the object is between O and F, or outside the centre O.

All these effects can be verified experimentally by receiving the image on a card in the manner described above. It is evident that in all these cases the images are real.

If the object L M be placed between F and B, as in fig. 7, the pencils of rays which diverge from the several points of the object will be reflected, diverging as if they had radiated from the corresponding points of an image, *l m*, at a certain distance behind the reflector. This image will be similar in position with the object, that is erect, and it will be greater than the object in its linear dimensions, in proportion to its distance from the centre O of the reflector.

Fig. 7.



Since the image in this case is behind the reflector it will be imaginary.

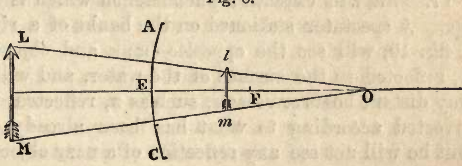
If the object be moved towards B, the image will also move towards B, and if the object be moved towards F, the image will move from B, and will recede through spaces much greater than

those through which the object is moved. In fine, when the object approaches to F, the image will recede indefinitely behind the reflector, and will disappear altogether when the object actually arrives at F.

All these phenomena admit of easy verification, by placing a candle in the several positions here assigned, and observing its image reflected in the mirror.

13. If the reflector be convex, the object L M (fig. 8), will have its image at the points *l m*, between the reflector and the principal focus F.

Fig. 8.



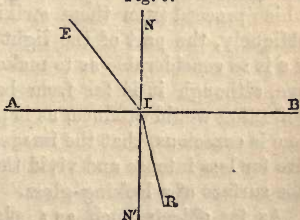
The rays proceeding from the several points of the object L M will, after reflection, diverge as if they had proceeded from the corresponding points of *l m*, and will produce upon the vision the same effects as if an object had been actually placed at *l m*.

The image in this case, therefore, will be erect, and it will be less than the object in the proportion of O *l* to O L. In this manner is explained the effect familiar to every one, that convex reflectors exhibit a diminished picture of the object placed before them.

14. IMAGES PRODUCED BY TRANSPARENT BODIES.

When light enters or issues from a transparent body its direction is deranged, its rays appearing to be broken at the points where they pass through the surface of the body. This effect is called refraction.

Fig. 9.



15. Thus, if the line A B (fig. 9) be supposed to represent the surface of such a body, and that a ray, E I, enter it at I, this ray, instead of preserving its direction, will be broken, as it were at I, and will take the direction I R. If the ray has been transmitted from R to I, it would, on issuing from the surface A B at I, have been broken, and would take the direction I E.

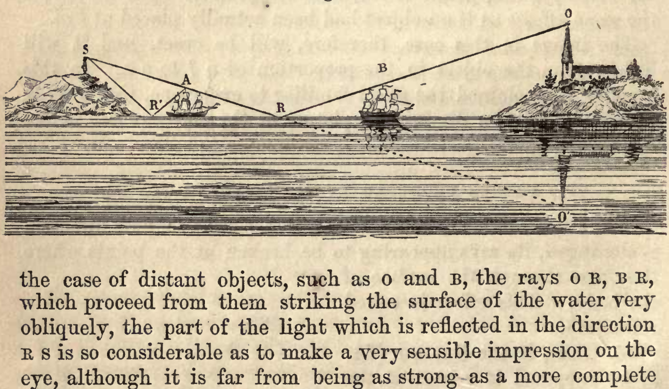
Let the line N N′ be drawn perpendicularly to the surface A B. If the ray E I be supposed to enter the surface at I, it will be always refracted *towards* the perpendicular I N′.

But if, leaving the direction R I, it issue from the surface at I, it will be refracted *from* the perpendicular I N in a direction such as I E. This is a law of refraction to which there is no exception.

16. Light will enter a transparent body whatever may be the obliquity with which it falls upon it; but it must be remembered that a certain proportion of it will be reflected. This proportion is very small, when the light strikes the body with very little obliquity, but it increases as the obliquity is increased, and is very considerable at great obliquities.

17. This will explain a phenomenon which is familiar to every eye. A spectator stationed on the banks of a river or lake, as at S, fig. 10, will see the opposite bank and objects such as O upon it, reflected in the surface of the water, and will see in the same way distant boats or vessels, such as B, reflected, the images being inverted according to what has been already explained (6, 7). But he will not see any reflection of a near object, such as A. In

Fig. 10.



the case of distant objects, such as O and B, the rays O R, B R, which proceed from them striking the surface of the water very obliquely, the part of the light which is reflected in the direction R S is so considerable as to make a very sensible impression on the eye, although it is far from being as strong as a more complete reflection would produce, as is proved by the fact of which every one is conscious, that the images of objects thus reflected in water are far less intense and vivid than images would be reflected from the surface of a looking-glass.

As for objects, such as A, placed near the spectator, they are not seen reflected, because the rays A R′, which proceed from them, strike the water with but little obliquity, and consequently the part of their light which is reflected in the direction R′ S towards the spectator is not sufficiently considerable to produce a sensible impression on the eye.

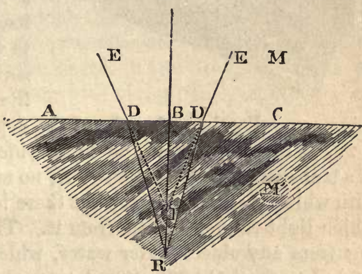
For this reason, also, a person on board a vessel may see

plainly enough the banks or shores reflected in the water; but if he lean over the bulwark, and look down, he cannot see his own image.

18. In general, the illustrations and imagery of poetry, drawn from natural phenomena, are just and true. Yet this is not invariably the case. Every one will perceive from what has just been stated, that the fable of the Dog and the Shadow, which has been handed down through so many ages, diffused through so many languages, and taught so universally in the nursery and the school, is a most gross optical blunder.

19. If a visible object be placed below a transparent body, as, for example, at the bottom of a reservoir of water, or attached to the lower surface of a plate of glass, an observer above will see, not the object itself, but an optical image of it, which will be nearer to the surface, or less deep than the object. A reservoir of water, a river, or a lake, or the sea, when not too deep to allow the bottom to be visible, will on this account always appear to be less deep than it really is, because the optical image of the bottom, which is in fact what the observer sees, is less deep than the bottom itself. After what has been stated above, this is easily explained.

Fig. 11.



Let R (fig. 11) be a point of any object below the surface A C of any transparent body. The rays R D, which diverge from R, will, after emerging, be deflected *from* the perpendicular in the directions D E, and will enter the eye of an observer as if they came from I, a point less deep than R. The point R will, therefore, be seen as if it were at I, and the same being true of all the points of the object, it follows that an optical image of the object will be formed at a certain depth below the surface, less than the depth of the object.

This image will evidently be imaginary, since the rays by which it is produced diverge from the surface of the transparent body, but not from the points of the image.

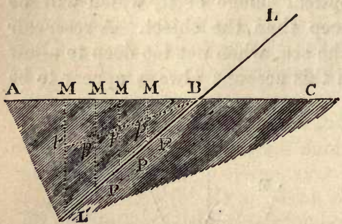
The greater the refracting power of the body is the more the rays D E, emerging from the surface, will be deflected from the perpendicular, and consequently the nearer the point I of their divergence, or, what is the same, the image, will be to the surface.

20. Thus, for example, if the transparent medium be water, the depth of the image will be about three-fourths of the depth of the object, and consequently water, when the bottom can be seen, always appears less deep than it is in the proportion of 3 to 4. A reservoir, whose real depth is 12 feet, will appear to have a depth of only 9 feet.

If the transparent body be glass, which has a greater refracting power than water, in the proportion of about 8 to 9, an object attached to the under-surface will appear to be at the depth of about two-thirds of the thickness of the glass.

21. If a rod L B L′, fig. 12, be plunged obliquely in water, it will appear as if it were broken at B, the part immersed being seen, not as it really is in the direction B L, but in the direction B l'. This will be easily understood, when it is considered that the image of such point of the rod will appear at a less depth than the point itself, in the proportion of 3 to 4. Thus the image of the several points P will be at the points p, the depths M p being severally three-fourths of the depths M P.

Fig. 12.



22. A certain part of the light which strikes upon the surface of a transparent body will enter it, no matter what be the obliquity with which it encounters it; but there is a certain obliquity beyond which light cannot emerge from it. Thus a ray of light proceeding from any object under water, which strikes the surface at an angle less than 41° 32′, cannot emerge, and in that case it may be asked, what becomes of the ray? The answer is, that it will be reflected back into the water exactly as if the surface were a perfectly polished plane surface.

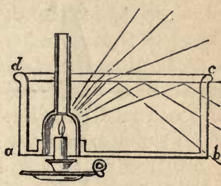
In the same manner, if the transparent body be glass, the ray cannot emerge from it, if the obliquity be less than 48° 11′, and in this case the ray will be reflected.

The reflection which takes place under such circumstances, is much more complete than any reflection from the surfaces of bodies, whether naturally smooth or artificially polished. It has, consequently, though somewhat improperly, been called PERFECT REFLECTION, for, although the reflection is incomparably more perfect than that from smooth or polished surfaces, nevertheless there is still a small part of the light lost.

The angle which limits the obliquity at which light can emerge from a transparent body, is called the limit of transmission.

23. This remarkable property of transparent bodies may be illustrated experimentally by the apparatus represented in fig. 13; let *a b c d* represent a glass vessel filled with water, or any other transparent liquid. In the bottom is inserted a glass receiver, open at the bottom, and having a tube such as a lamp-chimney carried upwards and continued above the surface of the liquid. If the flame of a lamp or candle be placed in this receiver, as represented in the figure, rays from it penetrating the liquid, and proceeding towards the surface *d c*, will strike this surface with various obliquities. Rays which strike it under angles of incidence within the limits of transmission will issue into the air above the surface of the liquid, while those which strike it at greater angles of incidence will be reflected, and will penetrate the sides of the glass vessel *b c*.

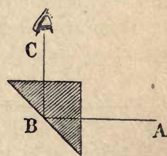
Fig. 13.



An eye placed outside *b c* will see the candle reflected on that part of the surface *d c*, upon which the rays fall at angles of incidence exceeding the limit of transmission; and an eye placed above the surface will see the flame, in the direction of the reflected rays, striking the surface with obliquities within the limit of transmission.

24. A remarkable property of glass prisms, which proves of great use in various optical instruments, depends on this property. Let B, fig. 14, be a rectangular prism, the longest face of which is inclined at angles of 45° to the two rectangular faces. If a ray of light, A B, enter one of the rectangular faces perpendicularly, it will pass into the glass without suffering any change of direction, and will encounter the surface B at an angle of 45°, which being less than 48° 11′, the minor limit of possible transmission, it will be reflected on issuing through the other rectangular surface perpendicularly, will meet the eye as it would if B were the only surface it had encountered, and the object from which the ray has proceeded, and whose real direction is B A, will be seen in the direction C B at right angles to B A.

Fig. 14.

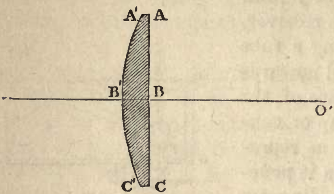


25. IMAGES PRODUCED BY LENSES.

A lens is a circular plate of glass, the surface of which is curved on one side or both.

26. A plano-convex lens, fig. 15, has one side, A C, flat, and the other convex.

Fig. 15.

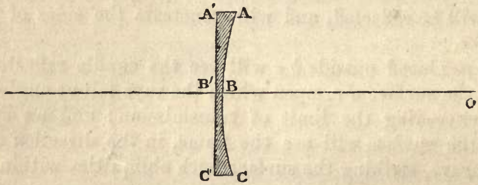


A plano-concave lens, fig. 16, has one side, A′ C′, flat, and the other concave.

A double convex lens, fig. 17, has both sides convex, and a double concave lens, fig. 18, both sides concave.

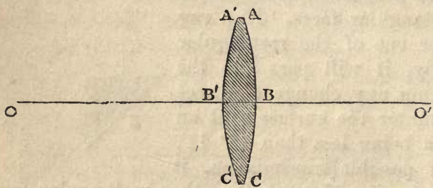
It is not necessary that the convexities of the sides in the one, or the concavities in the other, should be equal. The degree of convexity or concavity will depend on the radius O B or O′ B′ of the sphere of which

Fig. 16.



the lenticular surface is a part. The less that radius is, the greater will be the curvature of the surface. Thus, if O B be greater than O′ B′, the surface A′ C′ will be more convex (fig. 17), or more concave (fig. 18), than A C.

Fig. 17.



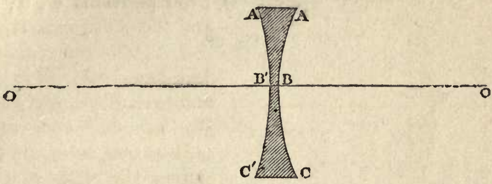
A concavo-convex lens has one side, A C, fig. 19, concave and the other convex, the concavity, however, being greater than the convexity.

A meniscus has also one side, A C, fig. 20, concave, and the other convex, but, on the contrary, the convexity is greater than the concavity.

27. A line, O O′, which joins the centres of the two lenticular surfaces in figs. 17, 18, 19, and 20, and which passes through the centre of the lenses, and one which, in figs. 15 and 16, is drawn from the centre O at right angles to the flat surface, and passing through the centre of the lens, is called the AXIS OF THE LENS.

28. Examples of each of these forms of lenses are more or less familiar to every one. Thus the glasses of spectacles used by

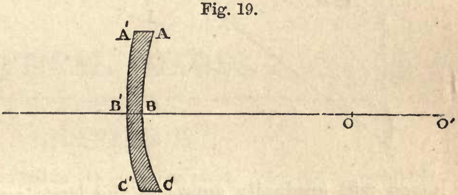
Fig. 18.



weak-sighted or aged persons, are usually double convex lenses. Those used by short-sighted persons are generally double concave lenses.

Spectacles called periscopic are sometimes used. The glasses of these, which are suited to weak sight, are meniscus, and those adapted to short sight are concavo-convex lenses.

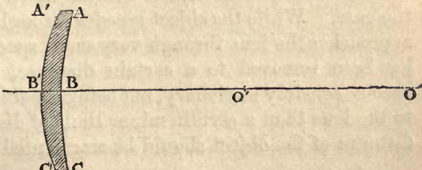
Fig. 19.



The eye-glasses of opera-glasses are usually double concave lenses. The object glasses are generally plano-convex lenses, the plane side being turned inwards.

29. If an object such as O‴, fig. 21, be placed before a convex lens, and at right angles to its axis, an image, I‴, of it will be produced behind the lens, also at right angles to the axis, inverted in position in relation to the object, that is, the top of the image corresponding with the bottom of the object, and the right side with the left, and *vice versâ*.

Fig. 20.



If the object be placed near the lens, the image will be formed at a great distance from it, and will be greater than the object in its linear dimensions in the same proportion as its distance is greater than that of the object from the lens.

This will be evident by inspecting the figure. The length of the image, I‴, is evidently greater than that of the object, O‴, in

the same proportion as that in which the distance I‴L is greater than O‴L.

If we suppose the object O‴ to be gradually removed from the lens, so as to assume successively the positions O″, O′, &c., the

Fig. 21.

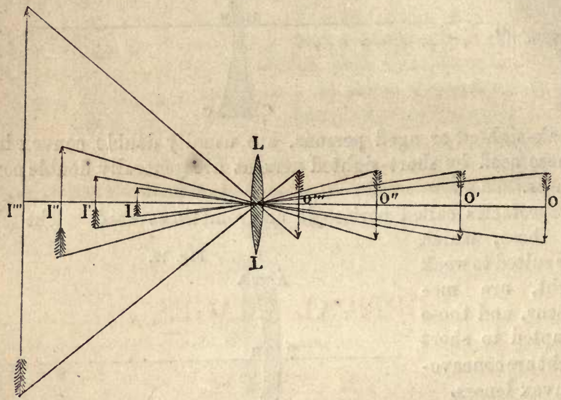


image will gradually approach the lens, assuming successively the positions I″, I′, &c., and the linear dimensions of the object and image being still in the proportion of their distances from the lens, the image will necessarily decrease as the distance of the object from the lens increases.

30. Now, it might be imagined that by removing the object to distances increased without limit, the distance of the image from the lens would be decreased without limit. This, however, is not the case. While the object recedes through great spaces, its image approaches the lens through very small spaces, and when the object has been removed to a certain distance, the image is found to become sensibly stationary, not being capable of approaching nearer to the lens than a certain minor limit of distance, even though the distance of the object should be augmented indefinitely.

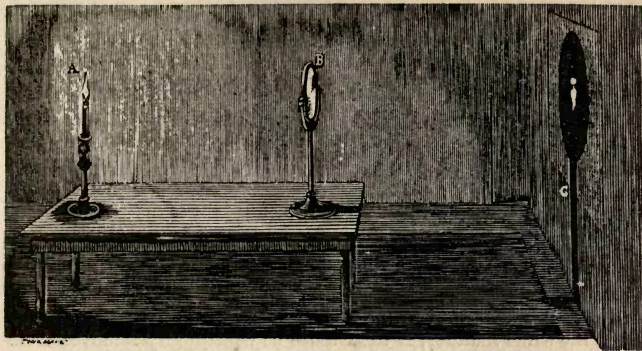


Fig. 22.

OPTICAL IMAGES.

CHAPTER II.

31. Experimental verification. — 32. Variation of the magnitude of the image.—33. Principal focus and focal length.—34. Variation of position, and magnitude of image.—35. When images real, and when imaginary. — 36. Images produced by concave lenses. 37. Focal length varies with refracting power.—38. Refracting power depends on material of lens.—39. Spherical aberration.—40. Images produced by lenses not absolutely clear and distinct.—41. Series of images.—42. Nebulous and confused effect.—43. Spherical aberration greater near the borders. —44. Increases with the curvature. —45. And with the magnifying power.—46. Spherical distortion.—47. Curved images.—48. How to diminish spherical aberration.—49. Lenses made from diamonds and other precious stones.—50. Ineffectual attempts at improvement by this means.—51. Methods of diminishing spherical aberration by proper adaptation of curvatures.—52. Aplanatic lenses.—53. Chromatic aberration.—54. White light compound.—55. Coloured lights sometimes compound.—56. Images produced by homogeneous lights.—57. Images produced by compound light.—58. Lenses always produce several images of a natural object.—59. Why they are not always so confused as to be useless for vision.—60. Dispersion.—61. Dispersion increases with refraction.—62. Dispersion different with different material.

31. This remarkable property of lenses, which is of the most extreme importance, not only in the theory and practical construction and application of microscopes, but of all optical instruments whatsoever, admits of the easiest and most simple experimental verification.

Take any magnifying glass (the object lens unscrewed from an opera glass, or the spectacle glass, or eye-glass of a weak-sighted person will answer the purpose), and holding it with its surfaces vertical, let the flame of a candle be placed near it in its axis, and let a white card be held behind it at right angles to its axis. Let the card be moved gradually from the glass until the inverted image of the flame of the candle is seen distinctly upon it. In this position the flame may be supposed to be the object O‴, and its image on the card the image I‴. Let the candle be now removed a little farther from the glass. The image will become indistinct, but if the card be removed a little towards the glass, its distinctness will be restored. The flame will now represent O″, and its image on the card I″. See fig. 22, p. 97.

In the same manner, if the candle be continually removed from the glass, its image will approach continually to the glass, but at a slower and slower rate. When, however, the flame has been withdrawn to the distance of several yards from the magnifying glass, its image will become sensibly stationary, never approaching in any perceptible degree closer to the glass, however far the candle may be removed.

32. It must be observed, nevertheless, that although the *position* of the image of the flame remains thus unchanged by the increased distance of the candle from the glass, its *magnitude* undergoes a very perceptible change, decreasing in linear dimensions in exactly the same proportion as the distance of the candle from the lens increases.

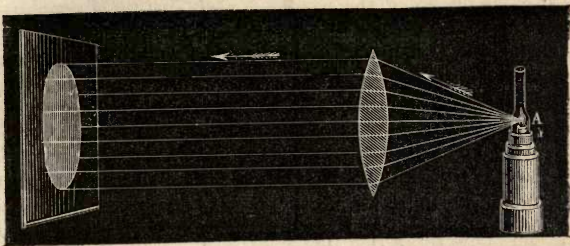
It appears, then, in fine, that when a convex lens is presented to any object, whose distance from it exceeds a certain limit, the optical image of such object will be formed at a fixed distance behind the lens, which distance will be the same whatever the distance of the object may be. Thus, for example, if the lens be presented to a window looking out over a landscape, the image of this landscape will be seen depicted, but inverted in position on a card held behind the lens, at the fixed distance from it, which has just been indicated; and although the trees, buildings, and mountains, which form the view before the lens, are at extremely various distances, their images will be all depicted on the card upon a small scale, at precisely the same distance from the lens.

33. The point in the axis of a lens, at which a distinct picture of distant objects is thus produced, is called the PRINCIPAL FOCUS * of the lens, and the distance of this point measured upon the axis from the lens is called the FOCAL LENGTH of the lens.

* In some practical works on the microscope, this point is called the SIDEREAL or SOLAR focus. This term has not, however, obtained a place in the nomenclature of scientific writers.

If a radiant point be placed at A, fig. 23, at the principal focus of a lens, the rays diverging from it after passing through the lens will be rendered parallel, as may be shown experimentally by receiving them upon a screen as indicated in the figure. An

Fig. 23.



illuminated disc will be produced upon the screen equal in size to the lens.

34. Having explained the change of position which the image undergoes by removing the object indefinitely *from* the lens, let us now consider how its position will be affected if the object be moved indefinitely *towards* the lens.

It is evident, from what has been already explained, that when a very distant object approaches the lens, no change whatever in the *position* of its image is at first produced, the image remaining always at the principal focus, but the *magnitude* of the image will be sensibly augmented, its linear dimensions increasing in exactly the same proportion as the distance of the object from the lens decreases.

When, however, the object has approached within a certain limit of distance, the image will begin, at first very slowly, and afterwards more rapidly, to recede from the lens. It will thus continue to recede, and at the same time to increase in its dimensions, until the object is brought to a distance from the lens equal to its focal length. The image having then augmented indefinitely in magnitude and distance, will altogether disappear.

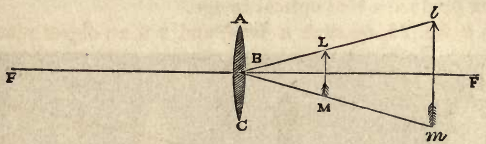
This is, therefore, an exceptional position of the object, in which no optical image is produced by the lens.

If we suppose the object to be brought still nearer to the lens than its focal distance, no actual optical image will be produced, but the rays of light which, having issued from the various points of the object, pass through the lens, will be refracted by it into directions such as they would have had if they had issued from a

similar object at a greater distance in front of the lens, and of proportionally greater dimensions.

To render this more clear, let A C, fig. 24, represent a convex

Fig. 24.



lens, whose focal length is B F, and let L M be an object placed before it at a less distance than B F. Now, it will be understood that from every point of the object L M, rays of light diverge, which, passing through the lens A B, have their directions changed by it, and this change is such that, instead of diverging from the various points of the object L M, they will diverge from a similar series of points placed at a greater distance before the lens. In fine, after passing through the lens, they will diverge as if they had issued from the points of an object *l m* in all respects similar to the object L M itself, and having a like position, but greater than the object in its linear dimensions, in the proportion of *l* B to L B; that is, of its distance from the lens to the distance of the object from the lens.

In this case, then, no actual optical image is produced which, as in the former case, can be received and exhibited upon a card. But if the eye of an observer be placed behind the lens, it will receive the rays proceeding from the object L M, and passing through the lens exactly as if they really had proceeded from the object *l m*, without the interposition of a lens, and the eye will be affected, and vision produced exactly as if such an object as *l m* were present.

35. When the optical image is actually formed, so that it can be received and exhibited upon a card or screen, it is said to be a REAL IMAGE; and when it is formed in the manner above described, so as to be seen by the eye directly receiving the rays from the lens, but not capable of being formed on a screen, it is said to be IMAGINARY.

An exception might be taken to the terms, inasmuch as the visual image is as real in the one case as in the other. They have, however, been generally adopted in the nomenclature of optics.

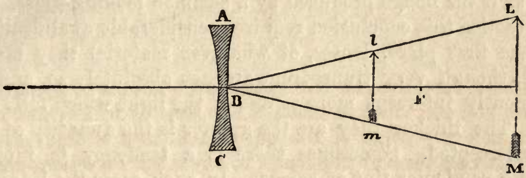
All that has been said of the optical images, real and imaginary, produced by double-convex lenses, and of their principal foci, will be equally applicable to plano-convex and meniscus lenses. In each of these the convexity being the prevalent character, their optical effects are similar to those of double-

convex lenses, subject, nevertheless, to some qualifications which will be explained hereafter.

36. The optical effect of a concave is, as might be expected, the reverse of that of a convex lens. In no position can a concave lens produce a real optical image.

Let A C, fig. 25, be such a lens, and L M an object placed any-

Fig. 25.



where before it. The rays which diverge from the various points of L M will, after passing through the lens, diverge as if they had issued from the corresponding points of a similar object *l m*, nearer to the lens; and an eye placed behind the lens will see the object, not as it is at L M, but as it would be if placed at *l m*, and reduced to a lesser magnitude.

This explains a fact which must be familiar to every one who may have looked through concave glasses, such for example as the spectacles of short-sighted persons. All objects seen through them appear to be diminished.

37. The focal length of a lens depends on the degree of refraction which it is capable of producing on the rays which pass through it. The greater this refraction is the more the convergence of the rays will be increased, and the less will be the focal length.

The refracting power of a lens depends partly on its form, and partly on the material of which it is made. With a given material the refracting power will increase with the convexity. The more convex the surfaces are the greater will be the refracting power, and the less the focal length and the nearer to the lens will the image of an object at a given distance be produced, the lens being supposed to be convex.

38. But the refracting power, and therefore the focal length, also depends on the material of the lens. Two lenses having the same convexity will have different refracting powers, and therefore different focal lengths, if they are made of different transparent bodies, or even of different sorts of the same substance. A lens of water will have a longer focus than a similar one of glass; and the latter will have a longer focus than a similar one made from a diamond, because water has a less refracting power than glass, and glass less than diamond. In the same way, a

lens of crown-glass will have a longer focus than a similar one of flint-glass, since the latter has a greater refracting power than the former.

39. SPHERICAL ABERRATION.

In all that has been stated hitherto, it has been assumed that the images produced by lenses are as perfect reproductions of the object as is the image produced by a common looking-glass.

In practice this conclusion requires considerable qualification.

In the first place, lenses, of whatever material they may be formed, though very transparent are not absolutely so, and they consequently intercept more or less of the light which falls upon them. The thicker they are the greater is the quantity of light thus intercepted. Sometimes there is a tendency to intercept light of a particular tint of colour. In such cases the brightness of the image is not only deteriorated, but it is falsely coloured, being most tinged with those colours which the material of the lens transmits most freely.

Although such imperfections cannot be totally removed, they may be and have been reduced to so very inconsiderable an amount by the proper selection and adaptation of the material of which lenses are formed, that they need not be farther noticed here.

The loss of light by reflectors, however highly polished the reflecting surface may be, greatly exceeds the amount of light intercepted by transparent media. On this, as well as some other accounts, refracting have been generally preferred to reflecting microscopes.

40. Although the image of an object produced by a convex lens in the manner already described (29), appears at first view to be an exact reproduction of the object, it is found, when submitted to rigorous examination, to be more or less confused and indistinct. This confusion is augmented in proportion as it is more magnified, and when it is viewed as in a compound microscope, with a simple microscope so as to be still further amplified, the confusion becomes so great as to deprive the observation of all utility.

This indistinctness and confusion arises from two causes, one depending on the form, and the other on the material of the lens.

That which depends on the form of the lens we shall now explain.

41. If a convex lens be presented to a visible object, the central part being covered by a disc of card, leaving uncovered a ring of surface at the borders, a distinct, but very faintly illuminated

image will be produced at a certain distance from the lens. Let this distance be called d'.

If the border of the lens be now covered with a ring of card, and the central part with a card disc less in diameter than the ring, so as to leave an uncovered space between the disc and the ring, another faint but distinct image will be produced at a certain distance d'', a little greater than d'.

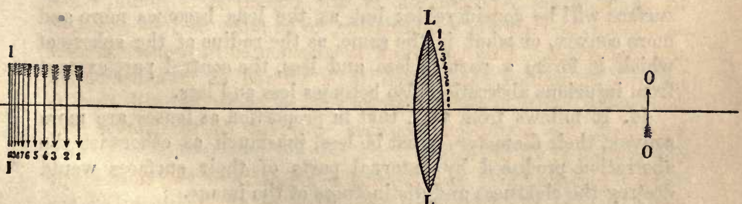
If the border be covered with a broader ring of card, and the central part by a still less disc, so as to leave an uncovered ring of surface smaller than the last, another image will be produced still faint and distinct, and at a distance d''' greater still than d''.

In fine, by continuing this process, it will be found that if the lens be resolved into a series of annular surfaces, concentric with each other and with the lens, a series of images will be produced at distances d', d'', d''', d'''', &c., gradually increasing, that produced by the external annulus being at the least distance, and that produced by the spot surrounding the centre at the greatest distance.

On comparing the series of distances d', d'', d''', d'''' . . . . at which these images are placed, a very important circumstance will be observed in their distribution. It will be found that while those produced by the central annuli are crowded very closely together, those produced by the annuli near the edge of the lens are separated one from another by much more sensible spaces.

When the entire surface of the lens is uncovered and exposed at once to the object, it is evident that this series of images will be produced simultaneously. Some idea of their distribution along the axis of the lens may be found by referring to fig. 26.

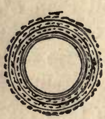
Fig. 26.



The object being O O, and the image produced by the small central spot of lenticular surface being at I I, the images formed by the rings of surface immediately contiguous to this spot will be crowded together so closely in front of a screen held at I I, that they will all be formed upon the screen with very little

less distinctness than the image formed by the central spot itself, so that by their superposition upon the screen, all will contribute to augment the brightness of the image formed upon it, without producing injurious confusion or indistinctness. But not so with the much more distant and more widely separated images 1, 2, 3, 4, &c., produced by the exterior rings of the lenticular surface. These being at very sensible distances from the screen held at the place of the central image would produce a confused, cloudy, and indistinct picture on the screen, which falling upon the more distinct picture produced by the central part, would give the whole a nebulous and misty appearance, such as is shown in fig. 27, when the object is a circular disc.

Fig. 27.



42. It appears therefore that a distinct optical image of an object placed before a convex lens can only be formed when a certain limited part of the central lenticular surface is exposed to the object. The exterior part would render the image brighter by means of the increased light transmitted to it, but at the same time confused by reason of the distance of the place of the distinct image formed by the borders from that formed by the centre.

The confusion and indistinctness produced in the optical image of an object from the cause here explained and illustrated is called the SPHERICAL ABERRATION.

43. From what has been explained, it appears that the aberration produced by the central part of the lens is inconsiderable, but that it increases rapidly towards the borders. The extent of the central surface, which is thus free from any considerable aberration depends on the convexity of the lens. If it be but slightly convex, or what is the same, if the radius of the sphere of which it forms a part be great, the extent of this central surface will be considerable; but as the lens becomes more and more convex, or what is the same, as the radius of the sphere of which it forms a part is less and less, the central part exempt from injurious aberration also becomes less and less.

44. It follows from this, that in proportion as lenses are more convex, their diameters must be less, inasmuch as otherwise the aberration produced by external parts of their surfaces would destroy the clearness and distinctness of the image.

Since every increase of the magnifying powers of a lens formed of a given material requires an increase of its convexity, it will also render necessary a decrease of its diameter.

45. If while the diameter is thus decreased the focal length remained the same, the aperture and consequently the illumination of the image would be diminished. But while the increased

convexity renders a diminished diameter necessary it also produces a diminished focal distance; and since the aperture (that is, the angle formed by lines drawn from the principal focus to the extremities of a diameter of the lens) increases with the decrease of the focal distance, this decrease may compensate for the decrease of the diameter, so that the aperture may not be diminished. But in fact the decrease of focal distance, much more than compensates for the decrease of the diameter, and in good lenses the aperture is much greater for small lenses of high magnifying power, than for larger ones with lower magnifying power.

It is owing to this, that great magnifying powers can be obtained without rendering the illumination of the image injuriously faint, as it would be, unless the aperture of the lens on which it depends were augmented in some degree proportionate to the increase of the power.

46. SPHERICAL DISTORTION.

Independently of the spherical aberration properly so called, there is another optical effect produced in the image, depending on the form of the lens, which requires notice.

In the preceding paragraphs it has been assumed that the *form* of the image is that of the object, and when the image is small this may be considered as practically true. But when the image is considerably amplified the form differs sensibly from that of the object.

If an object which is straight or flat be presented to a convex lens, outside its principal focus, so that a real image shall be produced on the other side of the lens, the image will not be flat but curved, with its concavity towards the lens. If the object were curved with its convexity towards the lens, its image would be also curved, but with its concavity towards the lens, and the curvature of the image would in that case be greater than that of the object.

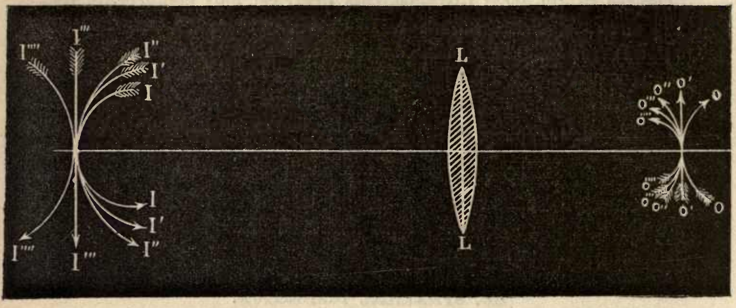
If the object were concave towards the lens, its image would be also concave towards the lens, but with less curvature than the object.

47. If the curvature of the object be supposed gradually to increase, the concavity still being presented towards the lens, the image will be also concave towards the lens, but its curvature will diminish as that of the object increases, and when the curvature of the object increases to a certain point, the image will become straight or flat.

If the curvature of the object still continue to increase, the image will become convex towards the lens, and its curvature will increase with that of the object.

The relative forms of the object and its image in such case will be more clearly understood by reference to fig. 28, where L L is

Fig. 28.



the lens, and O O, O′ O′, O″ O″, O‴ O‴, and O⁗ O⁗, objects having the different forms above mentioned, placed at a point beyond its principal focus. The images of these severally are indicated by the letters I I, I′ I′, I″ I″, I‴ I‴, and I⁗ I⁗, at the other side of the lens. Thus the image of the straight or flat object O′ O′ is the curved image I′ I′, concave towards the lens L L. In like manner, I I, concave towards L L, is the image of the object O O, which is convex towards L L; I″ I″, concave towards L L is the image of O″ O″, also concave towards L L; while the flat image I‴ I‴ is that of the object O‴ O‴, which is curved and concave towards L L. The image I⁗ I⁗, convex towards L L, is that of O⁗ O⁗, concave towards L L.

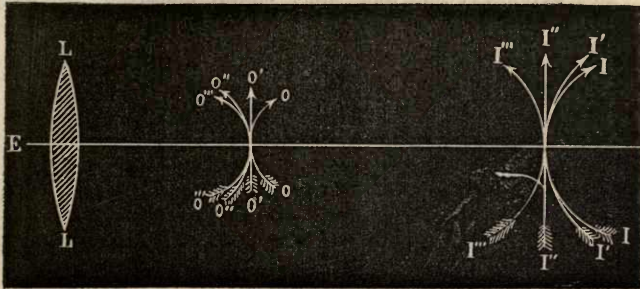
It will be evident that none of these images could be projected with uniform distinctness upon a flat screen, except that of the curved object O‴ O‴, the image of which is flat. If the image of a flat object O′ O′ were projected upon a screen held at the point where its curved image I′ I′ intersects the axis of the lens, it would only be distinct at and near the centre. The screen being behind the extremities would be out of focus with them, and consequently those parts of the image would be indistinct. If the screen were advanced, so as to render the extremities distinct, the centre would be out of focus, and consequently indistinct.

In this case, the object is assumed to be placed beyond the focus of the lens, and consequently the image is always real, whatever be its form. Let us now consider the case in which the object is placed within the focus, and its image consequently imaginary (34).

Let L L, fig. 29, be the lens, and let the object, placed within its

focus, be viewed by an eye at E, an imaginary image will be seen at a certain distance, greater than that of the object.

Fig. 29.



If the object be straight or flat, such as O′ O′, the image will be curved with its convexity turned towards the lens, as shown at I′ I′, in the figure. If the object be concave towards the lens, the image will be less and less convex, until the object having a certain concavity, such as O″ O″, the image will be straight or flat as shown at I″ I″. If the concavity towards the lens be still greater, as at O‴ O‴, the image will become concave towards the lens, but less so than the object. If the object be convex towards the lens, as at O O, the image I I will also be convex towards it.

It follows, therefore, that a straight or flat object seen through a convex lens thus will appear curved or convex, and that a convex object will appear more convex. A concave object, provided it have a certain degree of curvature, will have a straight or flat image, and all objects more concave will have concave images.

These results will be found to have considerable importance in the practical construction of compound microscopes.

48. From what has been explained it follows, that if any expedient could be discovered, by which the focal length of a lens could be shortened without increasing its convexity, we could obtain a given magnifying power with a lens of a given diameter without increasing the aberration, a result which would be a most evident advantage. Now, there is only one way by which this could be accomplished, which is by finding some material for the lens, which without any countervailing disadvantages would have a greater refracting power than glass. A lens made of such a material would have a shorter focus, and consequently a greater magnifying power than a lens of glass with the same convexity.

49. Several transparent substances having this important property are found among the precious stones, and more particularly in the diamond, which has a greater refracting power than any known transparent body.

This advantage, and some other optical properties, induced some scientific men, among whom Sir David Brewster held a conspicuous place, to cause lenses to be made of diamond, sapphire, ruby, and other precious stones, and sanguine hopes were entertained of vast improvements in microscopes, resulting from their substitution for glass lenses. These hopes have however proved delusive.

50. Notwithstanding all that enterprise, skill, and perseverance could accomplish, both on the part of scientific men, such as Sir David Brewster, and practical opticians, such as Pritchard and Charles Chevalier, the attempt has been abandoned. Independently of the cost of the material, difficulties almost insuperable arose from the heterogeneous nature of the gems. Their double refraction, and the imperfect transparency and colour of some of them. The improvement of simple microscopes composed of glass lenses by the invention of doublets, and by the proper combination and adaptation of their curvatures, was also such as to render their performance little, if at all inferior even to the gem lenses, while their cost is not much more than a twentieth of that of the latter.

In all cases, therefore, where objects or parts of objects of extreme minuteness are submitted to microscopic examination, requiring the application of high magnifying powers combined with extreme precision of definition, the compound microscope must be resorted to.

51. Although it is not possible to efface altogether the effects of spherical aberration, yet they have been so considerably diminished by the adaptation of the curvatures of the lenticular surfaces, that in well-constructed optical instruments they may be regarded as entirely removed for all practical purposes. This is accomplished by giving to the two sides of the lens different curvatures, so adapted that the aberration produced by one shall be more or less counteracted by the aberration produced by the other.

It has resulted from a mathematical analysis of the phenomena, that the lens which has least spherical aberration is double convex with unequal convexities, the radius of the flatter side being six times that of the more convex side. If the object to which such a lens be presented be very distant from it, and consequently the image proportionately close to it, the more convex side should be presented to the object. This, for example, is the case in all forms of telescopes and opera-glasses. But if, as is

always the case in the microscope, the object be placed much nearer to the lens than its image, the flatter side of the lens should be presented to the object.

With such a lens the entire extent of the aberration, the object being distant, does not exceed its thickness by more than the 14th part. If the thickness of the lens be expressed by 1, the aberration for a distant object will be 1·07.

Such a lens is represented in fig. 30, and it will be evident in how slight a degree it differs from a plano-convex lens. It may therefore be expected that its aberration cannot differ much from that of the latter form of lens, which has the advantage of being much more easily worked. It is accordingly found by calculation that the aberration of a plano-convex exceeds that of a lens of the above form, in the proportion of 27 to 25, or something less than a twelfth.

Fig. 30.

If a plano-convex be used the flat side should be presented to the object if it be near, and the convex side if it be distant.

52. Lenses, or combinations of lens, which thus practically efface the effects of spherical aberration are said to be APLANATIC, from two Greek words α (a) and πλάνη (plánē), which signify *no straying.*

53. CHROMATIC ABERRATION.

It has been already shown in a former number of this "Museum," that solar light is a compound principle, consisting of several component lights differing one from another as well in colour as in their susceptibility of refraction, and that the colours of all natural objects arise from their peculiar properties of reflecting light, red objects being those which reflect red light, blue those which reflect blue light, and so on, a white object being one which reflects indifferently lights of all colours, and a black object one which reflects no light.

54. White light is composed of lights of various tints, varying from red to violet in the following order: red, orange, yellow, green, blue, indigo, and violet, each colour being less refrangible than that which follows it.

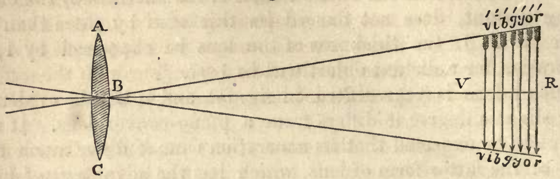
55. Coloured lights may be also more or less compounded; thus, various tints of orange may be produced by the combination of reds and yellows, tints of green by the combination of yellows and blues, and so on.*

56. This being understood, let us suppose an object illuminated

* See Tract on "Colour."

by a simple and homogeneous red light placed before a convex lens A C, fig. 31, and that an image of it is produced at *r r'*. Let

Fig. 31.



the same object be now supposed to be illuminated by simple and homogeneous orange light. This light being more refrangible than red light, the lens A C will produce an image *o o'* of the object, a little nearer to it than *r r'*. If the object be next illuminated with simple and homogeneous yellow light which is still more refrangible, the image *y y'* will be produced at a still less distance from the lens, and in fine if the object be successively illuminated with simple green, blue, indigo and violet lights, the images will be produced successively at *g g'*, *b b'*, *i i'*, and *v v'*, nearer and nearer to the lens as the light is more refrangible.

57. If the object, instead of being illuminated as we have here supposed it to be by a simple homogeneous light, be illuminated by any light compounded of two or more simple lights, then so many distinct images of it will be produced at different distances from the lens, as there are simple lights in the compound, and these images will differ in colour from the object and from each other. Thus, for example, if the object be illuminated by a compound light of a green tint, composed of simple yellow and blue lights, two images of it will be produced, the nearer blue, and the more distant yellow.

A like consequence will follow if the object be illuminated by a compound light made up of three simple lights, when three images will be formed, and so on.

If then an object reflect from its surface the white solar light, which is a compound of all the colours, it will follow that all the coloured images which have been here produced in succession, will be produced at one and the same time, and will be placed one before the other in a regular series at unequal distances from the lens, as already described.

58. It has been shown * that the colours of natural objects generally are more or less compounded. It is only in very rare

* See Tract on "Colour."

and exceptional cases that the light emitted or reflected by any body is pure homogeneous light. It follows, therefore, from what has been explained above, that as many distinct images of each object will be produced by a lens as there are distinct homogeneous colours which enter into the composition of the light it emits or reflects, and that these several images will be placed at several different distances from the lens corresponding with the different refrangibilities of the different homogeneous lights of which they are composed.

If different parts of the same object be differently coloured, different series of images of those parts will necessarily be produced at different distances from the lens, according to their several component colours.

59. From all this it might be inferred that the optical utility of lenses would be utterly destroyed in the case of all objects save such as would emit or reflect homogeneous light. For if such a multitude of variously coloured images be formed at various distances from the lens, the effect which would be produced upon a card held at any distance whatever, might be supposed to be a confused patch of coloured light, having no perceptible resemblance in form or colour to the object; and such would certainly be the case if the distances of the several images, one from another, were considerable. These distances, however, are so small, that the coloured images are so blended together that the decomposition of their colours appears principally by coloured fringes produced upon their edges, and in general upon the outlines of their parts. Nevertheless, when these false lights and fringes are magnified, as in the compound microscope they always are, by the eye-glass, the general appearance of the object under observation would be so changed as to colour, and so indistinct as to outline, as to be rendered useless for all the purposes of scientific enquiry.

The indistinctness of the image thus produced, is called chromatic aberration, from the Greek word χρωμα (chroma) signifying COLOUR.

60. The extent of the chromatic aberration produced by a lens measured by the interval V R (fig. 31) between the red and violet images, is called the DISPERSION of the lens.

The preceding observations have been applied only to the images produced by a convex lens, but they are equally applicable to concave lenses, taking into account that the images in the case of these last are imaginary. Thus, if a white object be placed before a concave lens, the light issuing from it, after passing through the lens, will proceed as if it had diverged from different objects, leaving the seven colours placed at different distances from the

lens, but on the same side of it with the object, as explained in (36).

61. With the same lens the dispersion will increase with the refraction, and consequently the more the image is magnified the greater will be the dispersion and the aberration, and the more confused and indistinct the image.

62. It might naturally therefore be supposed that if two lenses made of different transparent substances produce images of the same object at the same distance from them, and consequently equally magnified, they would produce the same dispersion and aberration. It is found, however, that this is not the case. A lens of diamond and a lens of glass may be so formed that the same object being placed at equal distances from them, the distances at which the violet image will be produced shall be exactly equal, but the same equality will not prevail between the distances of the red image and those of the intermediate colours.

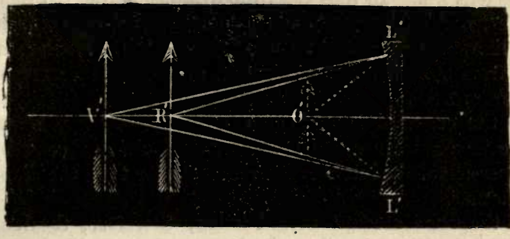


Fig. 36.

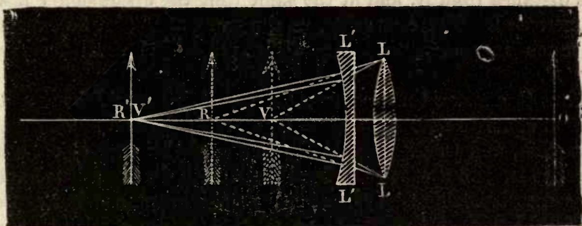


Fig. 37.

OPTICAL IMAGES.

CHAPTER III.

63. Experimental illustration.—64. Dispersive powers.—65. Dispersive power does not necessarily increase with refractive power.—66. Example of the diamond.—67. Achromatic lens.—68. Achromatic combination of flint and crown-glass.—69. Form of the compound lens.

63. To make this, which is a circumstance of the highest importance, more clear, let L L, fig. 32, and L′ L′, fig. 33, be two lenses, the former of diamond, and the latter of glass, and let O O and O′ O′ be a white object placed at the same distance before them. Let V be the violet, and R the red image, produced by the lens L L, the images of the intermediate colours being between V and R according to what has been explained above. Now let us suppose that such a convexity is given to the lens L′ L′, which is evidently always possible, that the distance of the violet image V′ of O′ O′ from the lens L′ L′ shall be equal to that of the violet image V of O O

from the lens L L. In that case, the distance of the red image R′, from L′ L′, will be greater than that of the red image R from L L, and in like manner the distances of all the intermediate images of O′ O′ from L′ L′ will be greater than those of the corresponding images from L L.

Thus the coloured images of O′ O′ produced by L′ L′ will be spread over a greater space than those of O O produced by L L. The dispersion of the latter is therefore greater than the dispersion of the former.

With the same amount of refraction, therefore, the lens L′ L′ produces more dispersion than the lens L L.

If we suppose the convexity of the lens L L to be increased, the refraction will be increased, the image V will be produced at a less distance from it, and at the same time the dispersion V R will be increased. The convexity, as shown at L″ L″ (fig. 34), may be so much increased, that the dispersion V″ R″ shall be equal to V′ R′.

Thus it appears that a diamond lens, which would have a dispersion equal to that of a glass lens, would have a much greater refraction, and would produce the image of the same object much closer to it. In a word, the focal length of a diamond lens having the same dispersion as a glass lens, would be much shorter than the focal length of the latter; or, what is the same, with an equal focal length, the diamond lens would have a less dispersion.

64. It appears, therefore, in general, that lenses made of different transparent substances will have, under like conditions, different dispersions. The DISPERSIVE POWERS of any two transparent media, will be measured by the dispersions which lenses of the same focal length made from them would produce.

The actual DISPERSION produced by a lens must not be confounded with the DISPERSIVE POWER of the material of which the lens is formed.

The actual *dispersion* produced by a lens of a given material, varies with its focal length, and with the distance of the object from it, so that with the same lens there may be many different quantities of dispersion, and the quantity will also be different with different lenses of the same material. But the *dispersive power* depends on the material alone, and is altogether independent of the form of the lens, its focal length, or the position of the object relatively to it. It will be most important that this distinction should be understood and remembered.

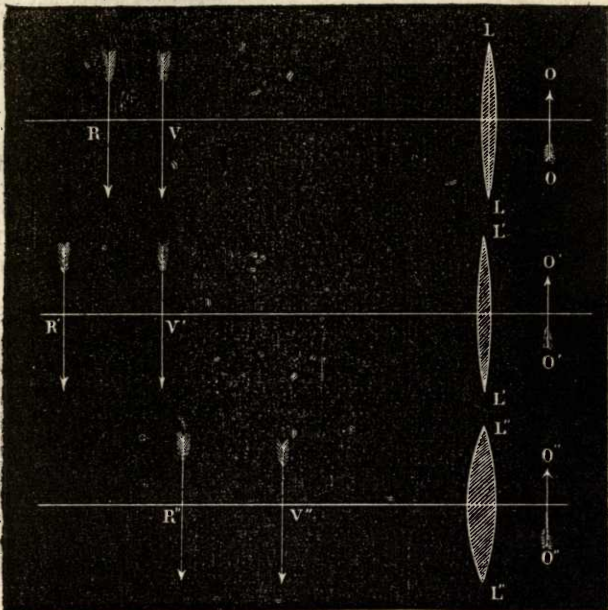
65. It might be imagined that the dispersive power would necessarily increase with the refractive power of the transparent body. On comparing together the optical effects of different media, no such correspondence is however found to prevail; on

the contrary, the bodies having nearly equal refractive powers, often have very unequal dispersive powers, and *vice versâ.*

Fig. 32.

Fig. 33

Fig. 34.



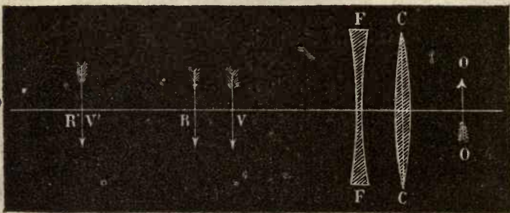
66. The high refracting power of the diamond, combined with its low dispersive power, were among the circumstances which raised the hopes already mentioned, that great improvements in microscopic lenses would result from the substitution of that gem and others, having like optical properties, for glass. Happily the invention of other and better expedients for surmounting the imperfections arising from chromatic aberration, have rendered unnecessary so expensive a remedy.

67. The discovery of the fact that the dispersive powers of different transparent bodies is not proportional to their refractive powers, but on the contrary, that bodies of greater refractive powers have sometimes lower dispersive powers, has supplied a remedy, which practically speaking, may be said to be completely efficacious for the removal of all the injurious effects of chromatic aberration. The manner in which this important end has been

attained, admits of an explanation, which after what has been stated above will be easily understood.

Let an object O O, fig. 35, be placed before a convex lens, C C, and let V be its violet, and R its red image, the dispersion being

Fig. 35.



consequently V R. Now, let F F be a concave lens, through which the rays proceeding from C C will be transmitted. This lens being concave, will have the effect of diminishing the convergency of the rays, and of throwing both the violet and red images to a greater distance; but it will have a greater effect on the violet than on the red rays, the former being more refrangible. Now, suppose that the material of which the lens F F is made, be such that at a certain distance from it, at V′ for example, the quantity of dispersion it would produce would be exactly equal to V R. In that case it is evident that the extreme images of O O, the violet image and the red image would be equally affected in contrary directions by the two lenses C C and F F. By C C, the violet image would be brought back, and the red image thrown forward, so as to separate them by the distance V R; but by the lens F F, on the contrary, the violet image is thrown forward, and the red driven back, in exactly the same degree, so that the two images are made to coalesce at R′ V′. As to the intermediate images, although they do not actually coalesce, their dispersion becomes so insignificant as to produce no perceptible chromatic aberration.

The production of this effect depends on the relative dispersive and refractive powers of the material of the two lenses, and on their forms.

This important principle may be further elucidated as follows:

Let L′ L′ (fig. 36, p. 113) be a diverging lens and let it be supposed to receive rays proceeding from a white object which, if not intercepted, would produce a real image of the object at a point O, within the focal distance of the lens L′ L′. In that case the lens L′ L′, according to what has been explained, will produce a series of coloured images of the object at a greater distance

from the lens, the red image R′ being nearest, the violet V′ most distant from the lens, the dispersion being R′ V′. Now this dispersion may be increased or diminished by increasing or diminishing the concavity or the diverging power of the lens L′ L′. It is evident, therefore, that such a form may be assigned to the lens L′ L′, as will give the dispersion R′ V′ any desired magnitude.

Let L L and L′ L′ (fig. 37, p. 113) be two lenses made of different materials, the former being a convergent, and the latter a divergent lens. Let O be a white object placed at such a distance from the lens L L, that its violet and red images would be formed at V and R, the distance V R being therefore its dispersion. But instead of allowing the rays transmitted through the lens L L to form this series of images, we will suppose them intercepted by the lens L′ L′, and since the images would fall within its focal length, the effect of L′ L′ will be to throw the images to a greater distance from it; but its effect upon the violet image V, will be so much greater than its effect upon the red image R, that the distance of V from the lens will be more increased than that of R, by a space exactly equal to V R, and consequently the two images will be made to coalesce, and the system will thus be rendered, for all practical purposes, achromatic. We say for all practical purposes, inasmuch as although the conditions here supposed will produce the coincidence of the red and violet images, they will not rigorously produce the coincidence of all those of the intermediate colours. Nevertheless, the general effect will be the production of an image sensibly exempt from chromatic confusion.

A compound lens, which produces such an effect, is called an ACHROMATIC LENS.

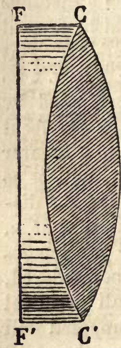
68. The materials which have been found most valuable for achromatic lenses, are flint and crown-glass, which differ considerably in both their refractive and dispersive powers. The refractive and dispersive powers of these sorts of glass, vary according to the proportions of their constituents, but they may always be rendered such as to fulfil the conditions necessary for an achromatic lens.

69. The forms of the lenses shown in fig. 38, are those of a plano-concave of flint, and a double convex of crown glass. It is neither necessary nor expedient that these forms should be adhered to. The crown-glass lens may be double-convex with unequal convexities, or it may be plano-convex or even meniscus. The flint-glass lens may be in like manner double-concave, with unequal concavities, or it may be plano-concave, or concavo-convex. In the same way the curves of the surfaces may be indefinitely varied, the compound lens having still the same focal

length. In the figure, the convex lens is next to the object. This is neither necessary nor usual. They are commonly placed in the contrary position.

The artist has therefore a wide latitude in the construction of achromatic lenses, of which the most eminent opticians have availed themselves with consummate skill and address, so as to efface by the happy combination of curves, not only the spherical aberration, but also the chromatic aberration of the eye-glass, and the spherical distortion of the final image in the compound microscope, as we shall show in our Tract on that instrument.

Fig. 38.



One of the forms of compound lens, which calculation shows to be most free from aberration, is a combination of a double-convex lens of crown-glass, with equal convexities, and a double-concave of flint-glass; the concavity of one face corresponding with the convexity of the crown lens, the radius of the concavity of the other face being $23\frac{1}{2}$ times that of the crown lens. But since such a concavity within the limits of the face of the lens would (fig. 30) be practically undistinguishable from a plane surface, opticians have combined a plano-concave of flint with the double-convex of crown-glass, which gives all the achromatism that can be desired.

An achromatic lens of this kind is shown in section in fig. 38, where C C is the double-convex crown, and F F the plano-convex flint lens.

The discovery of the method of constructing achromatic object-glasses for telescopes and microscopes, constitutes a most important epoch in the history of the progress of physical science. The refraction of light without the production of coloured fringes, which was regarded by Newton, his contemporaries, and his immediate successors, as incompatible with the established properties of light, was first shown to be possible, and, as it appears, even experimentally proved by Mr. Hall, a country gentleman of Worcestershire, about the year 1730. Three years later, he caused an achromatic telescope to be constructed by one of the London makers. Nevertheless, from some cause not known, this discovery proved fruitless, and the matter was neglected and forgotten.

The practical realisation of achromatism in telescope lenses is undoubtedly due to John Dollond, who arrived at their construction through a long course of skilful and systematical experiments undertaken for the express purpose. The possibility of solving the problem had been proved theoretically previous to this by Euler, upon reasoning based upon the structure of the eye.

After Dollond's discovery, the subject was investigated mathematically by Euler, Clairaut, and D'Alembert, but their researches did not lead to any practical improvement, and for a long series of years the lenses produced by the Dollond family enjoyed a monopoly and a European celebrity.

The difficulty in constructing achromatic lenses arises from that of obtaining single pieces of flint glass which are pure and uniform throughout their entire dimensions. The slightest impurity, or want of homogeneity in the composition of the glass, produces a streaked and deformed image.

The method of producing pure flint glass even in pieces of moderate magnitude, long remained a secret with the Dollonds, and it formed a very considerable article of exportation. Of late years, however, the art of producing it has undergone immense improvement in Switzerland, Bavaria, and other parts of the Continent, by the successful experiments of Guinand, Frauenhofer, Cauchoix, Korner, D'Artigues, and others. The object-glasses of Dollond, excellent as they were, never could be obtained of greater diameter than about 5 inches. Frauenhofer, however, has succeeded in producing perfect lenses, having diameters measuring from 12 to 13 inches. An object-glass, manufactured by Cauchoix, which measures more than 12 inches, is mounted in the great parallactic telescope of Sir James South, at Campden Hill.

The exact proportion of the ingredients composing these fine specimens is not certainly known, and the excellence of particular pieces depends on accidental circumstances not known or controlled by the makers themselves. Korner produced some of his best specimens with the following ingredients:—Quartz, previously treated with muriatic acid, 100; litharge, or red lead, 80; and bitartrate of potash, 30.

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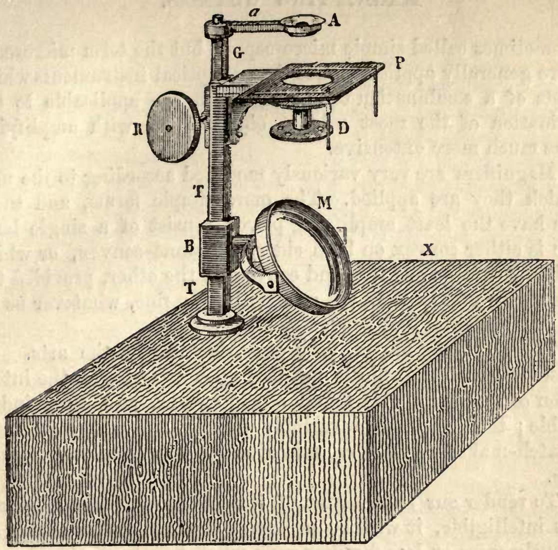


Fig. 15.—SIMPLE MICROSCOPE.

MAGNIFYING GLASSES.

1. Magnifiers intermediate between spectacle-glasses and microscopes.—2. Variously mounted.—3. Extensive use in the arts.—4. Their magnifying power explained.—5. Visual magnitude.—6. Standard of visual magnitude.—7. Distance of most distinct vision.—8. Visual magnitude at ten-inch distance.—9. Magnifying power of a convex lens.—10. Effect of the same lens with different eyes.—11. Superficial and cubical magnifying power.—12. The eye to be placed close to the lens.—13. Magnifying power depends on focal length.—14. Focal length depends on convexity and materials of lens.—15. Lenses of different materials.—16. Spherical aberration less with a greater refracting material.—17. Diamond lens.—18. Magnitude of lens greater with more refracting material.—19. Advantages of gem lenses.—20. Superseded nevertheless by the improvement of compound microscopes.—21. Magnifiers for reading.—22. For miniature-painters and engravers.—23. For watch-makers, jewellers, &c.—24. Supports for these.—25. Pocket magnifiers.—26. Coddington lens.—27. Doublets.—28. Their optical effects.—29. Their advantages over single lenses.—30. Method of mounting them; triplets.—31. Mounting of hand-doublets.—32. Method of mounting doublets of high power for dissection and similar purposes.

1. MAGNIFYING glasses hold an intermediate place between the spectacle glasses, used by weak-sighted persons, and the microscope; and when they possess considerable magnifying power, they

are sometimes called simple microscopes; but the term microscope is more generally applied to that class of optical instruments which consists of a combination of lenses, which are applicable to the examination of the most minute objects, and with amplifying powers much more extensive.

2. Magnifiers are very variously mounted according to the uses to which they are applied. The more simple forms, and those which have the least amplifying power, consist of a single lens, which is either convex on both sides, or plano-convex, or which may be concave on one side and convex on the other, provided the convexity be greater than the concavity. In fine, whatever be its form, it is essential that convexity shall prevail.

3. These glasses are of very extensive use in the arts. In all cases in which the objects operated upon are minute, the interposition of a magnifier is found advantageous, and often indispensable; thus, they are invariably used in different mountings by watch-makers, jewellers, miniature-painters, engravers, and others.

4. To render our explanation of these very convenient instruments intelligible, it will be necessary that the reader should be previously more or less familiar with what has been already explained in our Tracts on the Eye, on Optical Images, and on Spectacles; we shall, therefore, take for granted, that the contents of these Tracts are known to the reader.

We know no subject respecting which more inexact and erroneous notions prevail, than the amplification or magnifying effect produced by all optical combinations, from the simple convex lens to the most powerful microscope. The chief cause of all this confusion and obscurity may be traced to a neglect of the proper distinction between visual and real magnitude. The eye, as has been already explained, takes no direct cognizance of real magnitude, which it can only estimate by inference and comparison with the impressions of the sense of touch; these inferences and comparisons being often attended with complicated calculations and reasoning. If a proof of this be required, it may be found in the universally observable fact that objects which have the same visual magnitude often have real magnitudes enormously different; thus, for example, the apparent or visual magnitudes of the sun and moon are, as every one knows, equal; yet the real diameter of the sun is more than 400 times that of the moon.

5. It must be remembered that visual magnitude is determined by the divergence of lines drawn from the eye to the extreme limits of the object; it is measured, therefore, not like real magnitude by miles, feet, and inches, but by degrees, minutes, and seconds; thus, while the real diameter of the moon measures

about 2000, and that of the sun about 887000 miles, the visual diameter of the one and the other measures about half a degree.

The magnitudes of objects, as they appear with magnifying glasses, are all visual and not real. When an object seen by the interposition of such an instrument is said to be magnified so many times, it is therefore meant that it is so many times greater than it would be if the same object were seen with the naked eye; but since it has been shown in our Tract on the eye, that the visual magnitude of the same object seen with the naked eye varies, being greater as its distance from the eye is less, it follows, that the visual magnitude seen with the naked eye is an indefinite and variable standard, and in order that the visual magnitude of an object taken as the standard of magnifying power should be definite, it is necessary that the distance at which the object is supposed to be viewed by the naked eye should be stated. When, however, a person without any previous scientific instruction views an object with a magnifier, he becomes instantly conscious of its amplification; that is, that it appears larger than it would appear if he had viewed it without the interposition of the magnifier. The question is then, at what distance from his eye such a person would suppose the object to be looked at without the magnifier; and the reply which has been generally given to this question is, that he would suppose it to be viewed at that distance at which he would see it most distinctly.

6. This being admitted then, microscopists have generally agreed that the visual magnitude viewed with the naked eye, which should be taken as the standard of comparison in expressing the effect of magnifiers, is that which the object would have when viewed at the distance at which objects are most distinctly seen.

7. But here another difficulty arises. In the first place, the distance at which one individual can see an object most distinctly is not the same as that at which another will see it most distinctly; thus, while a far-sighted person will see most distinctly at the distance of 15 or 16 inches, and cannot see at all at the distance of 5 or 6 inches, a near-sighted person will see most distinctly at the latter distance, and only confusedly and indistinctly at the former. But even the same individual will see the same object most distinctly at one distance when it is strongly illuminated, and at a much less distance when it is feebly illuminated.

The distance of most distinct vision is therefore a variable and uncertain standard of comparison.

8. But there is one thing which is perfectly definite and certain. The visual magnitude of an object, at a given distance, is always the same, and quite independent of the powers and qualities of the eye which views it; it may, or may not, be distinctly

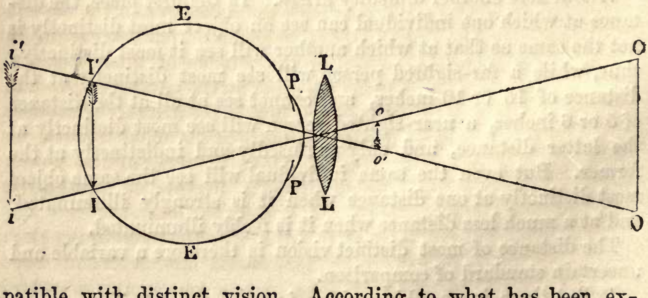
seen, or seen at all; but if seen, it can have but one visual magnitude. Thus an object, such as a coin, placed with its surface at right angles to the line of sight, at a distance from the eye equal to 10 times its own diameter, will have a visual diameter of $5\frac{3}{4}^{\circ}$, and neither more nor less, no matter by what eye it is viewed. Seeing, then, that the distance of most distinct vision varies with different observers, and even with the same observer under different circumstances, and cannot therefore be taken as a standard of reference for visual magnitude, it has been generally agreed that magnifying powers shall be arithmetically expressed, by reference to visual magnitudes seen at 10 inches distance. Thus, if we say that such or such a magnifier magnifies an object three or four times, it is meant that it exhibits that object with a visual magnitude three or four times as great as that which the same object would have if viewed with the naked eye at 10 inches distance.

This distance of 10 inches has not been selected arbitrarily. It is considered to be about the distance at which average eyes would see an object most distinctly. It has the further convenience of lending itself with facility to calculation by reason of its decimal form. In other countries, the same distance very nearly has been adopted as a standard. Thus, French microscopists take 25 centimetres, which is a very small fraction less than 10 inches, as their standard.

9. This conventional standard being accepted, let us see in what manner an object is made to appear magnified by the interposition of a single convex lens.

Let E E fig. 1, represent a section of the eye, and $o\ o'$ a small object placed at a much less distance from the eye than is com-

Fig. 1.



patible with distinct vision. According to what has been explained in former tracts, it will appear that the cause of indistinct vision is, in this case, that the image of $o\ o'$, produced by the humours of the eye, is formed not as it ought to be on the

retina at I I′, but behind it at *i i′*. According to what has been explained of optical images, the interposition of a lens, L L, of suitable convexity, will bring forward the image from *i i′* to I I′, and will therefore render the perception of the object distinct.

Now, it is most important to observe in this case, that the visual magnitude of the object, measured by the angle formed by the lines *o* I and *o′* I′, will be exactly the same as it would be if the eye could have seen the object *o o′* without the interposition of the lens: from which it appears that the lens does not, as is commonly supposed, directly augment the visual magnitude of the object, but only enables the eye to see the object with distinctness at a less distance than it could so see it without the interposition of the lens. We say *directly*, because, although the lens does not augment the visual angle of the object in the position in which it is actually viewed, yet, by enabling the eye to see it distinctly at a diminished distance, the visual angle of distinct vision, and therefore the apparent magnitude of the object, is increased in exactly the same proportion as the distance at which it is viewed is diminished.

To understand the magnifying effect of the lens, we must consider that the observer, seeing the object *o o′* with perfect distinctness, obtains exactly the same visual perception of it as if the object having the same visual magnitude were placed at that distance from the eye at which his vision would be most distinct. Let the lines passing through the extremities of the object therefore be prolonged to this distance of most distinct vision, and let an object, O O′, be supposed to be placed there, similar in all respects to the object *o o′*, and having the same visual magnitude. It will be evident, from what has been stated, that *o o′*, as seen with the lens, will have precisely the same appearance as the object O O′ would have if seen with the naked eye. The observer, therefore, considers, and rightly considers, that the magnifying power of the lens is expressed by the number of times that O O′ is greater than *o o′*; or, what is the same, by the number of times that the distance of O O′ from the lens, that is the distance of most distinct vision, is greater than the distance of the object from the lens.

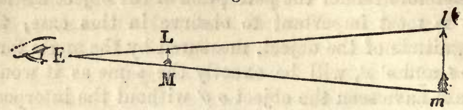
It follows, therefore, generally, that the magnifying power of the lens will be found by dividing the distance of most distinct vision by the distance of the object from the lens.

10. Adopting this method of estimating the magnifying power, it would follow that the same lens would have different magnifying powers for different eyes, inasmuch as the distance of most distinct vision for short sight is less than that for average sight, and less for average sight than for far sight.

To make this more clear, let E, fig. 2, represent an average

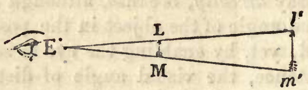
sighted eye; E′ (fig. 3) a short-sighted eye, and E″, fig. 4, a far-sighted eye. Let the same small object, L M, be placed at the same

Fig. 2.



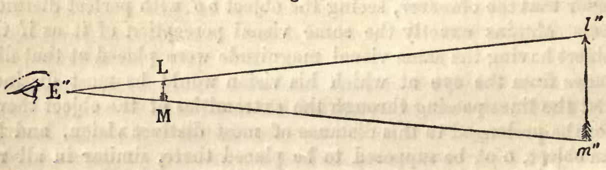
distance from each of them, and let the distance of most distinct vision for the first be E *l*; for the second E′ *l*′, and for the third

Fig. 3.



E″ *l*″. If, by the interposition of a lens, the object L M be rendered distinctly visible to each of these three eyes, it will appear at *l m*

Fig. 4.



to E, at *l*′ *m*′ to E′, and at *l*″ *m*″ to E″; its apparent magnitude, therefore, to the three eyes will be in the exact ratio of their respective distances of most distinct vision, and consequently the magnifying power to E′ will be less, and to E″ greater than to E.

It must, however, be observed, that in this, which is the commonly received explanation, a circumstance of some importance is omitted, which will modify the conclusion deduced from it. To produce distinct vision with a given lens, L L, the distance of the object from the lens will not be the same for different eyes; for short sight the object must be nearer, and for long sight more distant than for average sight.

Now, if this variation of the distance from the lens, or of the focus, as it is called, for different eyes vary in the same proportion as the distance of most distinct vision (and it certainly does not differ much from that proportion), it will follow, contrary to the received doctrine, that the magnifying power of the same lens, will be the same for all eyes, whether they have average sight, long sight, or short sight.

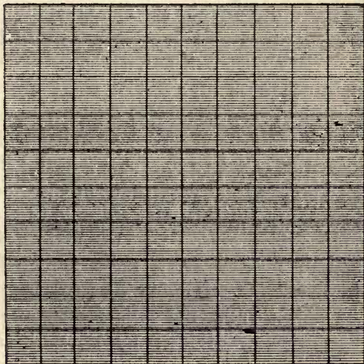
11. It is contended by some that the magnifying power is more properly and adequately expressed by referring it to the superficial than to the linear dimensions of the objects.

To illustrate this, let us suppose the object magnified to be a square such as *a*, fig. 5. Now, if its linear dimensions, that is its sides, be magnified 10 times, the square will be increased to the size represented at A (fig. 6); its height and breadth being each increased 10 times, and its superficial magnitude being consequently increased 100 times, as is apparent by the diagram.

Fig. 5.

a

Fig. 6.



A

Now, it is contended, and not without some reason, that when an object, such as *a*, receives the increase of apparent size, represented at A, it is much more properly said to be magnified 100 than 10 times.

Nevertheless, it is not by the increase of superficial, but of linear dimensions that magnifying powers are usually expressed. No obscurity or confusion can arise from this, so long as it is well understood that the increase of linear, and not that of superficial dimension, is intended. Those who desire to ascertain the superficial amplification, need only take the square of the linear; thus, if the linear be 3, 4, or 5, the superficial will be 9, 16, or 25, and so on.

It might even be maintained, that when an object having length, width, and thickness, a small cube or prism of a crystal for example, is magnified, the amplification being produced equally on all the three dimensions, ought to be expressed by the cube of the linear increase; thus, for example, if the object, being a cube, be magnified 10 times in its linear dimensions, it will acquire 10 times greater length, 10 times greater breadth, and 10 times greater height, and will consequently appear as a cube of 1000 times greater volume.

In this case, however, as in that of the superficial increase, the calculation is easily made by those who desire it, when the linear increase is known.

12. In all cases in which magnifying lenses are used, except where the lens is large, and the magnifying power low, the eye of the observer should be placed as close as possible to the lens, the pupil being as nearly as possible concentric with the lens; for since the pencils of rays, which proceed from the extreme points of the object, intersect at an angle equal to that formed by lines drawn from the extremities of the object to the centre of the lens, they will diverge after passing through the lens, at the same angle; and the farther the eye is removed from the lens, the more rays it will lose, and beyond a certain limit of distance, a part only of the object will be visible.

13. Since eyes of average sight are adapted to the reception of parallel rays, an object seen through a lens by them will be distinctly visible, only on the condition that its distance from the lens shall be equal to the focal length; for, in that case, the rays which diverge from each point of the object, will emerge from the lens parallel, and therefore suitable to the power of the eye.

It is for this reason that the magnifying powers of lenses are estimated, by comparing their focal lengths with the distance of distinct vision. For since the focal length is always the distance of the object from the lens for average eyes, the distance of distinct vision, divided by it, will, according to what has been explained, be the magnifying power of the lens for such eyes.

14. The focal length of a lens will be less in proportion as its refracting power upon the light transmitted through it is greater; but the refracting power of the lens depends partly on its convexity and partly on its material.

With the same material the refracting power will be greater and the focal length less, as the convexity is increased; and, on the other hand, with a given convexity, the refracting power will be greater, and the focal length less, as the refracting power of the material, of which the lens is made, is greater. Thus, for example, if two lenses be composed of the same sort of glass, that which has the greater convexity will have the less focal length; and if, on the other hand, two lenses, one composed of glass and the other of diamond, have equal convexities, the latter will have a less focal length than the former; because diamond has a greater refracting power than glass.

15. It will be evident, from what has been explained, that if two lenses be formed of materials having different refracting powers, such for example as glass and diamond, so as to have equal focal length, that which has greater refracting power will have the less convexity.

If two lenses therefore be formed, having the same magnifying

power, one of glass and the other of diamond, the latter will have less convexity than the former.

From what has been explained on the subject of spherical aberration, in our Tract upon Optical Images, it will be understood, that the more convex a lens is, the less its diameter must be, for if its diameter exceeds a certain limit relatively to its convexity, the spherical aberration will become so great as to render all vision with it confused and indistinct. This is the reason why all lenses of high magnifying power and short focal length are necessarily small.

16. But since the spherical aberration depends on, and increases with the convexity of the lens, other things being the same, it follows that if two lenses, composed of different materials, have equal focal lengths, that which has the less convexity will also have less spherical aberration.

17. Now, as according to what has been explained above, a diamond lens has less convexity than a glass lens of the same focal length, it will, if it had the same diameter, have less spherical aberration, or, what is the same, it will admit of being formed with a greater diameter, subject to the same aberration.

18. In lenses of high magnifying powers, and which are consequently of small dimensions, any increase of the diameter which can be made without being accompanied with an injurious increase of aberration, is attended with the advantage of transmitting more light from each point of the object to the eye, and therefore of rendering the object more distinctly visible. It was on this account that, when single lenses of high magnifying power were thought desirable, great efforts were made to form them of diamond, and other transparent gems having a refracting power greater than that of glass.

19. Sir David Brewster, who first suggested the advantage of this, succeeded in getting lenses of great magnifying power, made of ruby and garnet; he considered those made from the latter stone to surpass every other solid lens: the focal length of some of those made for him was less than the 1-30th of an inch, the magnifying power being more than 300.

20. All these and similar efforts made by Messrs. Pritchard and Varley, aided by the genius and science of the late Dr. Goring, have, however, happily for the progress of science, been subsequently rendered unnecessary by the invention of methods of producing good achromatic object-glasses of high power for compound microscopes, so that the range of usefulness of simple microscopes, or magnifying glasses, is now limited to uses and researches in which comparatively low magnifying powers are sufficient.

21. The most feeble class of magnifying glasses are those occa-

sionally used for reading small type, by persons of very weak sight; they consist of double convex lenses of 5 or 6 inches focal length, and having consequently a magnifying power no greater than two; they are usually double convex lenses, from 2 to 3 inches in diameter, mounted in tortoise-shell or horn, with convenient handles.

22. Magnifiers of somewhat shorter focal length and less diameter, similarly mounted, are used by miniature-painters and engravers.

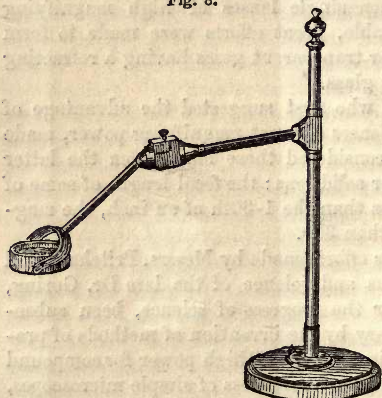
23. Lenses having a focal length of about one inch, set in a horn cell, enlarged at one end like the wide end of a trumpet, the magnitude being made to correspond with the socket of the eye, as represented in fig. 7, are used by watch-makers. The wide end being inserted under the eyebrow, is held in its position by the contraction of the muscles surrounding the eye-ball, and the minute work to be examined, is held within an inch of the lens set in the smaller end of the horn case; if the focal length be an inch, the magnifying power of such a glass, for average eyes, will be ten.

Fig. 7.

Glasses somewhat similarly mounted are used by jewellers, gem-sculptors, and other artists.

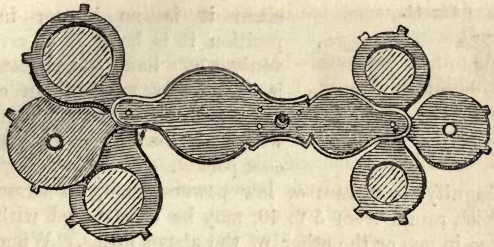
24. To relieve the artisan from the fatigue of holding the magnifier in the eye-socket or in the hand, a stand with a moveable socket is sometimes resorted to, such as that represented in fig. 8. A horizontal arm slides upon a vertical rod, upon which it can be fixed at any desired height by a tightening screw. This arm consists of two joints, connected together by a ball and socket, by which they can be placed at any desired inclination; at the extremity of the lower arm a fork supports a ring-shaped socket, made to receive the magnifier.

Fig. 8.



25. Very convenient pocket magnifiers are mounted in tortoise-shell or horn cases, in the form shown in fig. 9. Lenses of

Fig. 9.

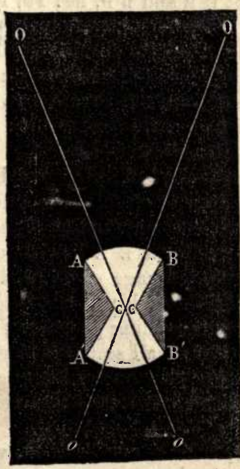


different powers are provided which may be used separately or together; when they are used together, however, the interposition of a diaphragm is necessary to diminish the effects of spherical aberration by cutting off the lateral rays.

Lenses thus mounted are well fitted for medical use, and for certain researches in natural history.

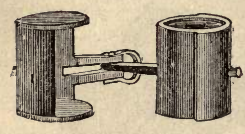
26. When a higher power is required than that which these common magnifiers afford, a magnifying glass, called from its inventor a Coddington lens, is used with much advantage. To produce such a lens, a solid ball or sphere of glass, about ½ an inch in diameter, is cut round its equator, so as to form round it an angular groove, leaving two spherical surfaces on opposite sides uncut. The angular groove is then filled up with opaque matter, the circular edge of the groove serving as a diaphragm between the two spherical surfaces. A section of such a lens is shown in fig. 10, where A B and A′ B′ are the two spherical surfaces left uncut, and A C A′ and B C B′ the section of the angular groove filled with opaque matter. The course of the rays passing through it from any point such as O, is shown by the lines O *o*, and it will be evident from the

Fig. 10.



mere inspection of the figure, that the effect of the lens upon the rays will be precisely the same, wherever the point O may be placed; this lens, therefore, gives a large field equally well defined in all directions, and since it is no matter in what position it is held, it is very convenient as a hand and pocket glass; it is usually mounted in a small case, such as is shown in fig. 11, which can be carried in the waistcoat pocket.

Fig. 11.



27. Magnifying glasses of low powers, such, for example, as those which range from 5 to 40, may be constructed with much advantage in one or the other of the above forms. When, however, higher powers are necessary, the use of such lenses, with very short focal length, is attended with much practical inconvenience, which has been removed by the use of magnifiers, consisting of two or more lenses combined. The combinations of this kind which are found most efficient, consist of two or three plano-convex lenses, with their convex side towards the eye; these are called doublets and triplets.

28. After what has been explained in our Tract upon Optical Images, the principle upon which these magnifiers depend will be easily understood.

Let E E and D D, fig. 12, represent the two lenses of a doublet, and let *o o* be a small object placed before D D, at a distance from it less than its focal length. According to what has been explained, D D will produce an imaginary image of *o o* at *i i*, more distant from D D than *o o*, so that an eye placed behind D D would receive the rays from *o o*, as if they had diverged from the corresponding points of *i i*.

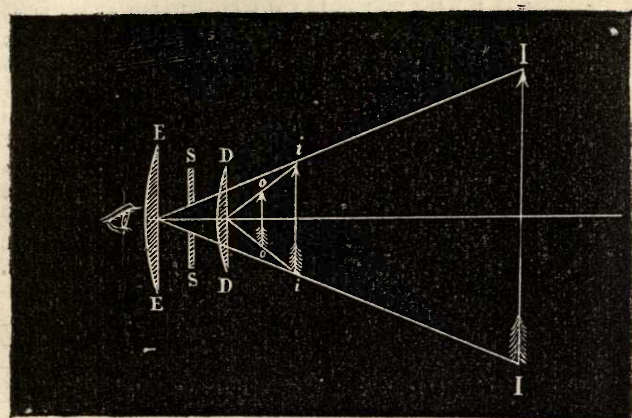
But instead of being received by an eye placed behind D D, these rays are received by the other lens E E; the image *i i* therefore plays the part of an object before the lens E E, and being at a distance from E E less than the focal length of the latter, an imaginary image of *i i* will be produced at I I; the rays, after passing through E E, entering the eye as if they had come from the corresponding points of I I.

To cut off all scattered rays not necessary for the formation of the image, a stop or diaphragm, S S, consisting of a circular disc of metal, with a hole in its centre, is interposed between the two lenses.

29. Such a combination, when high powers are necessary, has several advantages over an equivalent single lens. In the first place, the effect of spherical aberration is much less, and secondly,

the object can be placed at a much greater distance from the anterior lens D D, and can consequently be more conveniently

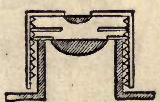
Fig. 12.



manipulated, if it be desired to dissect it, or to submit it to any other process; it can also be illuminated by a light thrown upon that side of it which is presented to the glass; this could not be done if it were nearly in contact with the glass, which must necessarily be the case by reason of its very short focal length, if a single lens were used.

30. It was recommended by Dr. Wollaston, the inventor of these doublets, to give the two lenses composing them unequal focal lengths, that of E E being three times that of D D.

Fig. 13.



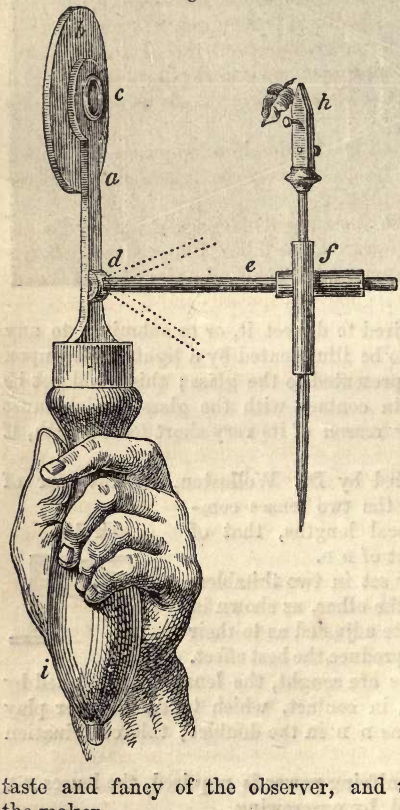
The lenses are usually set in two thimbles, one of which screws into the other, as shown in fig. 13, so that they can be adjusted as to their mutual distance, so as to produce the best effect. When still higher powers are sought, the lens D D is replaced by two plano-convex lenses, in contact, which taken together play the part of the single lens D D in the doublet; this combination is called the triplet.

When a very low magnifying power is required, the lenses E E and D D may be separated, by unscrewing.

31. The lenses, whether of a doublet or a triplet, being thus properly mounted, expedients must be adopted to enable the observer to apply them conveniently to the object under examina-

tion. The most simple method of effecting this would be to hold the lens to the eye with one hand, and to present the object before it at the proper distance with the other. But even in this case it would be necessary that the lens should be attached to a convenient handle, and unless the magnifying power were very low, the steadiness necessary to retain the object in the focus could not be imparted to it, and while the observation would be unsatisfactory the fatigue of the observer would be considerable.

Fig. 14.



When high powers are used, every motion of the object is as much magnified as the object itself, and consequently in such cases the most extreme steadiness is indispensable.

Whatever be the form of the mounting, therefore, it is necessary that the object should be supported by some piece attached to that by which the doublet itself is supported, so that it may be steadily held in the axis of the lenses, and that its distance from them may be varied at pleasure, by some smooth and easy motion, by which the observer can bring the object to the proper focus.

The means by which these ends have been attained vary according to the use to which the microscope is to be applied, to its cost, the taste and fancy of the observer, and the skill and address of the maker.

One of the most convenient forms of mounting, for a common hand microscope is shown in fig. 14.

The doublet is inserted in a socket *c* made to fit it; the screen

b protects the eye from the light by which the object is illuminated, an arm *e* is jointed at *d*, so that it can be turned flat against *a*, when the instrument is not in use, and can be inclined to *a*, at any desired angle. This arm being round, a sliding tube *f* is placed upon it, fixed to another tube at right angles to it, in which a vertical rod slides, to the upper end of which is attached a forceps or any other convenient support of the object under examination.

Several doublets or triplets of various powers may be provided, any of which may be inserted at pleasure in the socket *c*.

32. When still greater steadiness is required, and greater bulk and higher price do not form an objection, the arm and socket bearing the doublet are fixed upon a vertical pillar, screwed to a table with proper accessories for adjusting the focus and illuminating the object.

The arrangement adopted in the simple microscopes of Charles Chevalier, shown in fig. 15, p. 97, may be taken as a general example of this class of mounting.

The case in which the instrument is packed serves for its support when in use. A square brass pillar T T, screwed into the top of this case X, has a square groove cut along one of its sides, in which the square rod G is moved upwards and downwards by a rack and pinion R; at the top of this rod, a horizontal arm *a* is attached, at the end of which a socket is provided to receive the doublets; several of which having different powers are supplied with the instrument.

The object under observation is supported on the stage P, firmly attached to the upper end of the square pillar T T; in this stage is a central hole, through which light is projected on its lower surface when the object is transparent, and the quantity of this light is modified by means of an opaque disc D, pierced with holes of different magnitudes.

By turning this disc on its centre, any one of these holes may be brought under the object; when the object is not transparent, the opening in the stage is stopped, and it is viewed by light thrown upon its upper surface.

A square box B, sliding upon the pillar T T, with sufficient friction to maintain it at any height at which it is placed, carries a reflector M, by which light is projected upwards to the opening of the stage P, this light being more or less limited in quantity by the orifice of the diaphragm D, which is presented in its path.

In this instrument the object is brought into focus by moving the arm which carries the doublet up and down, by means of the rack and pinion R, the stage supporting the object being fixed The same effect might be, and is in some microscopes, produced

by moving the stage supporting the object to and from the lens: but when the instrument is applied to dissection, it is necessary to keep the subject dissected immoveable, and, therefore, not only to maintain the stage stationary, but to render it so solid and stable that it will bear the pressure of both the hands of the operator while he manipulates the dissecting instruments; on this account the stage is often made larger than is represented in the figure, and supported by a separate pillar.

The arm *a* carrying the doublet is also sometimes fixed in a square socket on the top of the rod G, so that it can be moved to and fro in the socket, while the socket itself can be turned upon the rod G; by this combination of motions, the observer can with great convenience move the lens over every part of the object under examination.

Simple magnifiers, with provisions similar to these, are made by the principal opticians, Messrs. Ross, Leland and Powell, Smith and Beck, Pritchard, Varley, and others.

When the object has not sufficient transparency to be seen by light transmitted through it from below, it may be illuminated by a light thrown upon it from above by a lamp or candle, and condensed, if necessary to obtain greater intensity, by means of a concave reflector or convex lens.

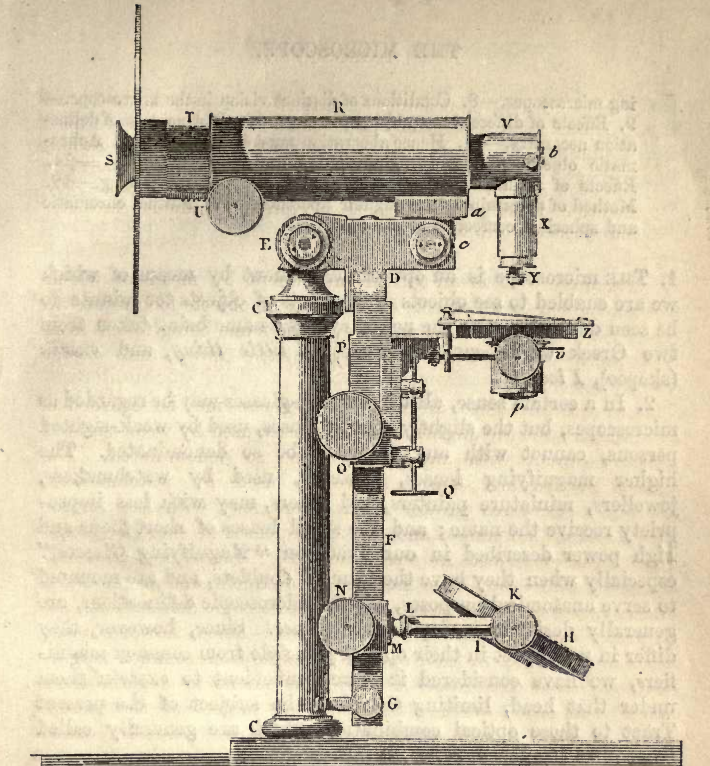


Fig. 37.—CHEVALIER'S UNIVERSAL MICROSCOPE.

THE MICROSCOPE.

CHAPTER I.

1. Origin of the term.—2. Simple microscopes are magnifying glasses.—3. Compound microscope.—4. Object-glass and eye-glass.—5. General description of the instrument.—6. Uses of the field-glass.—7. Reflect-

ing microscopes.—8. Conditions of distinct vision in the microscope.—9. Effects of different magnifying powers.—10. Distinctness of delineation necessary.—11. Hence aberration must be effaced.—12. Achromatic object-lenses. — 13. Sufficient illumination necessary. — 14. Effects of angular aperture.—15. Experiments of Dr. Goring.—16. Method of determining the angular aperture.—17. Mutual chromatic and spherical correction of the lenses.

1. THE microscope is an optical instrument by means of which we are enabled to see objects or the parts of objects too minute to be seen distinctly with the naked eye, the name being taken from two Greek words, μικρὸν (mikron), *a little thing*, and σκοπέω (skopeo), *I look at.*

2. In a certain sense, all magnifying-glasses may be regarded as microscopes, but the slightly convex lenses, used by weak-sighted persons, cannot with any propriety be so denominated. The higher magnifying lenses, however, used by watchmakers, jewellers, miniature painters, and others, may with less impropriety receive the name; and the small lenses of short focus and high power described in our Tract on "Magnifying Glasses," especially when they have the form of doublets, and are mounted to serve anatomical purposes, and for microscopic delineations, are generally designated *simple microscopes.* Since, however, they differ in no respect in their optical principle from common magnifiers, we have considered it more convenient to explain them under that head, limiting therefore the subject of the present Tract to those optical combinations which are generally called COMPOUND MICROSCOPES.

3. Such an instrument, in its most simple form, consists of a magnifying lens or combination of lenses, by means of which an enlarged optical image of a minute object is produced, and a magnifying lens, or combination of lenses, by which such image is viewed, as an object would be by a simple microscope.

4. The former is called the OBJECT-GLASS, or OBJECTIVE, since it is always directed immediately to the object, which is placed very near to it; and the latter the EYE-GLASS, or EYE-PIECE, inasmuch as the eye of the observer is applied to it, to view the magnified image of the object.

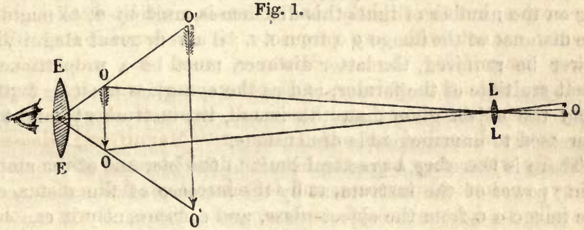
5. Such a combination will be more clearly understood by reference to fig. 1, where *o* is the object, L L the object-glass, and E E the eye-glass.

The object-glass, L L, is a lens of very short focal length, and the object *o* is placed in its axis, a very little beyond its focus. According to what has been explained in our Tract upon "Optical Images," 31 *et seq.* an image O O, of *o*, will be produced at a distance from the object-glass L L, much greater than the distance of

o from it: this image will be inverted with relation to the object; its top corresponding with the bottom, and its right with the left side of the object, and *vice versâ:* the linear magnitude of this image will be greater than that of the object, in the proportion of O L to *o* L, and consequently its superficial magnitude will be greater than that of the object, in the proportion of the squares of these lines.

The image O O, thus formed, may be considered as an object viewed by the observer, through the magnifying glass E E, and all that has been explained, relating to the effect of such a lens, in our Tracts on "Magnifying Glasses" and "Optical Images," will be applicable in this case. The observer will adjust the eye-glass

Fig. 1.



E E, at such a distance from O O, as will enable him to see the image most distinctly, and the impression produced upon his sense of vision will be that the image he looks at, is at that distance from his eye, at which he would see such an object most distinctly without the interposition of any magnifying lens; let this distance be that of a similar image O′ O′, and the impression will be that the object he beholds has the magnitude O′ O′.

The distance of most distinct vision with the naked eye, and the distance from the image at which the eye-glass must be placed to produce distinct vision, both vary for different eyes, but they vary almost exactly in the same proportion, so that the magnifying effect of the eye-glass upon the image O O, will be the same, whether the observer be long-sighted or short-sighted; in estimating the magnifying power, therefore, of such a combination, we may consider, in all cases, the distance of the eye-glass E E from the image O O, to be equal to its focal length, and the distance of O′ O′ from the eye-glass, to be 10 inches. (See "Magnifying Glasses," 8.)

To estimate the entire amplifying effect of such a microscope, we have only to multiply the magnifying power of the object-glass by that of the eye-glass; thus, for example, if the distance of the image O O from the object-glass be 10 times as great as the

distance of the object from it, the linear dimensions of the image O O will be 10 times greater than those of the object; and if the focal length of the eye-glass be $\frac{1}{2}$ an inch, the distance of most distinct vision being 10 inches, the linear dimensions of O′ O′ will be 20 times those of O O, and therefore 200 times those of the object; the linear magnifying power would in that case be 200, and consequently the superficial magnifying power 40000.

It would seem therefore, theoretically, that there would be no limit to the magnifying power of such a combination; practically, however, there are circumstances which do impose a limit upon it. It must be remembered that the object must always be placed at a distance from the object-glass, greater than the focal length of the latter, the magnifying power of the object-glass depending on the number of times this distance is multiplied, to make up the distance of the image O O from L L; if a very great magnifying power be required, the latter distance must be a proportionally great multiple of the former, and as the eye-glass must be farther from the object-glass than the image, the instrument might be increased to unmanageable dimensions.

There is therefore a practical limit to the increase of the amplifying power of the instrument by the increase of the distance of the image O O from the object-glass, and consequently it can only be augmented by the decrease of the focal length of the object-glass, combined with a corresponding decrease of that of the eye-glass. By such means, the distance of *o* from L L will be contained a great number of times in O L, while the latter has not objectionable length, and the distance of the eye-glass from the image O O will be contained a great number of times in the distance of most distinct vision.

The eye and object glasses are usually mounted at the distance of 10 or 12 inches asunder, adjustments nevertheless being provided, by which their mutual distance can be varied within certain limits.

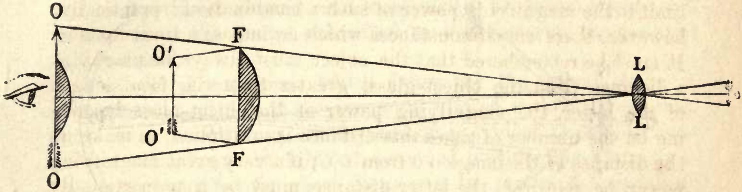
6. A convex lens is generally interposed between the object-glass and eye-glass, which receiving the rays diverging from the former, before they form an image, has the effect of contracting the dimensions of the image, and at the same time increasing its brightness. The effect of such an intermediate lens will be understood by reference to fig. 2, where F F is the intermediate lens. If this lens F F were not interposed, the object-glass L L would form an image of the object *o* at O O; but this image being too large to be seen at once with any eye-glass, a certain portion of its central part would only be visible. The lens F F, however, receiving the rays before they arrive at the image O O, gives them increased convergence, and causes them to produce a smaller

image O′ O′, at a less distance from the object-glass L L. The dimensions of this image are so small, that every part of it can be seen at once with the eye-glass.

The portion of the image which can be seen at once with the eye-glass, is called the FIELD OF VIEW of the microscope.

It is evident from what has been stated, that the effect of the

Fig. 2.



lens F F is to increase the field of view, since by its means the entire image of the object can be seen, while without its interposition the central parts only would be visible.

The lens F F has, from this circumstance, been called the FIELD-LENS.

But the increase of the field is not the only effect of this arrangement.

The light which would have been diffused over the surface of the larger image O O, is now collected upon that of the smaller image O′ O′; and the brightness, therefore, will be increased in the same proportion as the surface of O O is greater than the surface of O′ O′, that is, in the proportion of the square of O O to the square of O′ O′.

Another effect of the field-lens is to diminish the length of the microscope, for the eye-glass, instead of being placed at its focal distance from O O, is now placed at the same distance from O′ O′.

7. In this brief exposition of the general principle of the microscope, the image, which is the immediate subject of observation, is supposed to be produced by a convex lens; such an image, however, may also be produced by a concave reflector, and being so produced may be viewed with an eye-glass, exactly in the same manner as when produced by a convex lens.

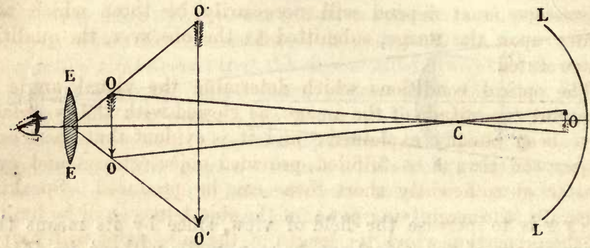
Microscopes have accordingly been constructed upon this principle, and are distinguished as REFLECTING MICROSCOPES; those in which the image is produced by a lens being called REFRACTING MICROSCOPES.

The principle of a reflecting microscope will be understood by reference to fig. 3, where L L is the concave reflector, of which C is the centre; the object *o* is placed towards the reflector, at a

distance from C greater than half the radius, and an inverted image of it is formed at O O, which, as in the case of the refracting microscope, is looked at with an eye-glass E E.

The great improvements which have taken place within the last twenty years in the formation of the object-glasses of refracting microscopes, have rendered these so very superior to reflecting

Fig. 3.



microscopes, that the latter class of instruments having fallen so completely into disuse, it will not be necessary here to notice them further.

In what has been explained, the general principle only of the microscope has been developed; many important circumstances of detail upon which its efficiency mainly depends must now be noticed.

8. The conditions which render the vision of an object with the microscope clear and distinct are essentially the same as those which determine the clearness and distinctness of our perception of an object with the naked eye. It will be found, by reference to our Tract upon "the Eye," that these conditions are three:—

1. That the visual angle should be sufficiently large;

2. That the outlines and lineaments of the object should be sufficiently distinct; and

3. That the object should be sufficiently illuminated.

It is evident that if any one of these conditions fail to be fulfilled, our visual perception of the object will be defective. If the object, for example, be exceedingly minute, though it be perfectly delineated and strongly illuminated, it will be either altogether invisible, or will appear as a mere speck.

If its outlines and lineaments be ill-defined, as when a tree or other object is seen through a mist, our perception of it will also be defective; and in fine, though it have sufficient magnitude and be perfectly delineated, we may fail to see it distinctly for want of sufficient light upon it, as when we look at objects towards the close of twilight.

The object which is submitted to our sense of vision with the microscope, being the optical image produced by the object-glass, our perception of it can only be clear and distinct, provided the three conditions above stated are fulfilled, that is, provided it be viewed under a sufficient visual angle, that its outline and lineaments be shown with perfect distinctness, and that it be sufficiently illuminated.

The conditions, therefore, upon which the efficiency of the microscope must depend will necessarily be those which will confer upon the image, submitted to the observer, the qualities above stated.

The optical conditions which determine the visual angle or apparent magnitude of the image, as viewed with the eye-glass, have been already explained; and it is evident that these conditions can always be fulfilled, provided object-glasses and eye-glasses of sufficiently short focus can be produced. Speaking generally, the magnifying power of the object-glass will be limited by the proportion which the length of the microscope will bear to its focal length; and the magnifying power of the eye-glass will be limited only by its power of approaching sufficiently close to the image, without too much contracting the field of view.

If the purpose of the observer were merely to see the object as a whole, so as to obtain a perfectly accurate notion of its outlines, a moderate magnifying power would, in general, suffice. But in most microscopic researches it is desired to ascertain, not merely the general outlines of the object, but the far more minute lineaments of its structure; and to render these visible in the minuter class of objects, amplifying powers of a very high order are indispensable.

9. The powers, indeed, which exhibit to the observer the general outline of an object, are rarely sufficient to show the minute lineaments of its structure. To perceive the general outline, it is necessary that the entire object should be included at once within the field of view, and this could not be the case, if the magnifying power exceeded a moderate limit. The power, on the other hand, which is sufficiently great to show the most minute parts of the structure, would necessarily be so great that a very small part only of the entire object would be comprised in the field of view.

From these circumstances it will be readily understood, that each class of powers have their peculiar uses, neither superseding the other; when we desire to observe the general form of a microscopic object, we must view it with a low power. When we desire, on the other hand, to examine its parts, and if, for example, it be an animalcule, to observe it member by member, and organ

by organ, we must call to our aid the higher class of power. In fine, a complete microscopic analysis of an individual object will require that it should be viewed successively with a series of gradually increasing powers.

10. But magnifying powers, to whatever extent they may be carried, will be of no avail if the image produced by the object-glass be not perfectly distinct and well defined; and it will be evident upon the slightest consideration, that any minute imperfections which may exist in its delineation, will be rendered more and more glaring and intolerable, the higher the magnifying power under which it is viewed.

With a common magnifying glass, or simple microscope, we view the object itself, and are subject to no other optical imperfections in our perception of it, than such as may arise from the imperfection of the lenses through which we view it; and since with such instruments the magnifying power can never be considerable, small defects of delineation are never perceptible. It is quite otherwise, however, with the class of instruments now under consideration, where magnifying powers, from 1000 to 2000 of the linear dimensions, are often brought into play.

These circumstances render it indispensable that the image of the object produced by the object-glass, and viewed through the eye-glass, should have the utmost attainable distinctness of delineation; not only as regards its outline, but also as respects the most minute details of its structure and colouring.

11. Now the solution of this problem, presented to scientific and practical men the most enormous difficulties; difficulties so great as to have been regarded, by some of the highest scientific authorities of the last half-century, as absolutely insurmountable. Happily, nevertheless, the problem has been solved; and without disparagement to the great lights of science, we must admit that its solution has been mainly the work of practical opticians. It is true that the general principles upon which the form and material of the lenses depend, were the result of profound mathematical research, but these principles were established and well understood at the moment when the practical solution of the problem was, by scientific authorities themselves, pronounced to be all but impossible. Opticians, stimulated by microscopists and amateurs, then applied themselves to the work, and by a long series of laborious and costly trials, attended with many and most discouraging failures, at length arrived at the production of optical combinations, which have rendered the microscope one of the most perfect instruments of philosophic research, and one, to the increasing powers of which, we can scarcely see how any limit can be assigned.

To appreciate the circumstances in which these great difficulties have consisted, it will be necessary that the reader should revert to our Tract upon "Optical Images," 39 *et seq.* It is there shown, that when an object is placed before a convex lens, the image of it which is produced, is not in any case a faithful copy of the object. In the first place, each portion of the lens, proceeding from its centre to its borders, produces a separate image; this series of images, being ranged at different distances from the lens: when these images are looked at, as they would be, for example, with the eye-glass of the microscope, they are seen projected one upon another, and being slightly different in their magnitudes, a confusion of outline and lineaments ensues, so that the object appears as though it were viewed through a mist.

This sort of indistinctness, called *spherical aberration*, has been fully explained in our Tract upon "Optical Images," and the general principles, by which its effects may be more or less mitigated, have been there explained.

It has been in the diminution, if not entire extinction, of this cause of indistinctness, by the happy adaptation of the curvatures of the lenticular surfaces entering into the optical combinations which form the microscope, that the address and genius of the practical opticians has been chiefly manifested; and if it cannot be stated, with strict truth, that all the effects of spherical aberration have been effaced in the best instruments now placed at the disposition of the observer, it may, at all events, be safely affirmed, that they exist in so small a degree as to offer no serious impediment to his researches.

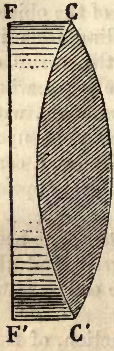
But independently of this source of indistinctness, there is another which has also been fully explained in our Tract upon "Optical Images," 39.

Light is a compound principle, consisting of several elements, differing in colour and also in refrangibility, the consequence of which is, that when an object is placed before a convex lens, it is not one image which is formed of it, but a series of images, varying in colour, from a violet or blue, through all the tints of the rainbow, to a red; these images are placed at slightly different distances from the lens, and when viewed through the eye-glass, would be projected one upon the other, and being of slightly different magnitudes, the consequence of such projection would be, that their outlines, and those of all their parts, would be more or less fringed with iridescent colours, an effect which, it is needless to say, would destroy the distinctness of the lineaments.

12. The principle upon which this chromatic aberration is counteracted, has been fully explained in our Tract upon "Optical

Images." It follows from what is there stated, that all confusion produced by this cause, can be removed by substituting for simple convex lenses, compound ones, consisting of a double convex lens of crown-glass C C′, fig. 4, cemented to a plano-concave lens of flint glass.

Fig. 4.



The image produced by such a combination, will be distinct and free from colour, provided that certain conditions be observed in the curvatures given to its component lenses.

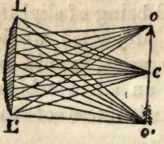
13. Assuming then, that by such combinations the image presented to the eye-glass is a faithful reproduction of the object, in its proper colours, perfectly distinct in all its lineaments, and sufficiently amplified, there is still one remaining condition for distinct vision, which is, that this image should be sufficiently bright. It will, therefore, be necessary here, to examine the conditions on which its brightness, or illumination, depends.

In the first place it is very evident that, other things being the same, the illumination of the image will be proportionate to that of the object, and in the inverse proportion of its superficial amplification; for the light which is transmitted from the object, being diffused over the surface of the image, will be necessarily more feeble as the superficial magnitude of the image is greater. The higher the magnifying power used, therefore, the greater is the necessity that the object should be intensely illuminated.

But the brightness of the image depends not only on the intensity of the illumination of the object, but also on the proportion of the light emanating from each point of the object, which arrives at the corresponding point of the image; and this, as we shall now show, will depend conjointly on the linear opening, or available diameter of the object-glass, and the distance of the object from it.

To make this more plain, let o o', fig. 5, be the object, and L L′ the object-glass. We are to consider that each point of the object is a centre, from which rays emanate towards the object-glass; thus, for example, rays issuing from the point c, form a cone, of which the object-glass is the base, and of which c is the vertex; supposing all these rays to pass through the object-glass, and to be refracted by it, they will converge to the point of the image which corresponds to c.

Fig. 5.



In the same manner, the rays which diverge from any other point, such as o, likewise form a cone, of which

that point is the vertex, and the object-glass the base, and after passing through the lens, they will converge to the corresponding point of the object.

Thus it appears that each point of the image is illuminated by as many rays as are included within such a cone as we have here described; that is to say, one whose base is the object-glass, and whose vertex is on the object. But it is evident that the number of rays included in such a cone, depends exclusively upon the magnitude of its angle, that is the angle L *c* L′, formed by lines drawn from a point, *c*, upon the object.

14. This angle, which forms, therefore, an element of capital

Fig. 6.

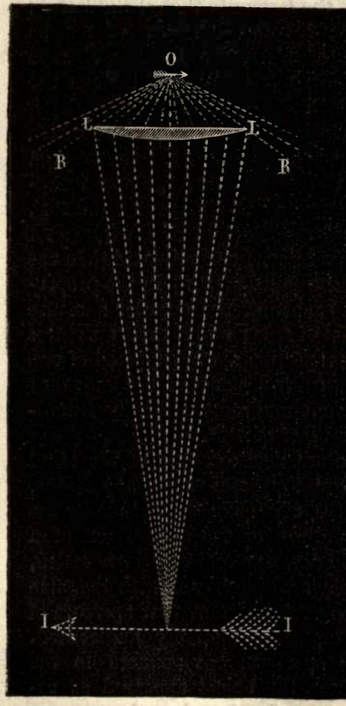
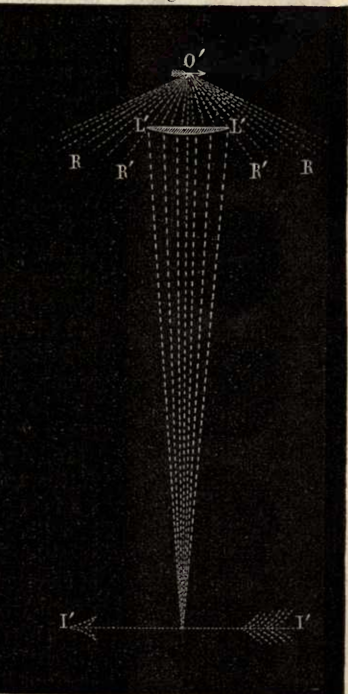


Fig. 7.

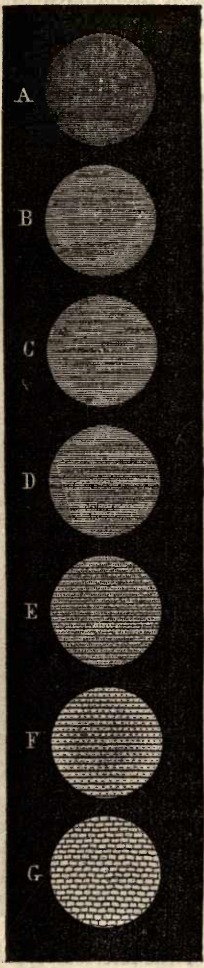


importance in the estimation of the efficiency of the microscope, is called the ANGULAR APERTURE of the object-glass.

The effect produced by the variation of the angular aperture of the object-glass, other things being the same, will be rendered

still more clearly intelligible by reference to figs. 6 and 7, where two lenses, L L and L′ L′, having equal focal lengths, are represented; the same object, O and O′, is placed at the same distances from them, and equal images of it, I I and I′ I′, are produced at equal distances from the lenses. The angular aperture of L L, being L O L, is greater than that of L′ L′, which is L′ O′ L′; and it is evident that a greater number of rays issuing from the object, will fall upon the lens L L, than upon L′ L′, in the proportion of the square of the angular aperture of the former to that of the latter; thus, if the angular aperture of L L be twice that of L′ L′, the number of rays which fall on L L will be four times the number which fall on L′ L′.

Fig. 8.



Supposing, then, that all the rays which fall upon each of the lenses, pass through them, and are made to converge upon corresponding points of the images I I and I′ I′, it is clear that each point of the image I I will be more intensely illuminated than the corresponding point of I′ I′, in the proportion of the square of the angular aperture of L L to that of L′ L′; and if these apertures be in the proportion above supposed of two to one, the several points of the image I I will be four times more intensely illuminated than those of I′ I′.

15. As a practical example of the effect of the angular aperture upon the image, we here give seven drawings made by the late Dr. Goring, of the appearance of a particle of dust, or a scale, as it is called, of a butterfly's wing, viewed with the same magnifying power, the angular aperture of the lens being successively augmented. When the aperture was reduced to the smallest limit, the object appeared as represented at A, fig. 8; when the aperture was increased in the proportion of 2 to 3, the object assumed the appearance represented at B, and, in short, by successively increasing the aperture, it assumed the appearances shown in C, D, E, F, and G. It will be

evident, therefore, that by the mere effect of this increased illumination, the lineaments showing the structure of the object, which were altogether imperceptible in C and D, began to be developed but very imperfectly in E, were more visible in F, and became quite distinct in G.

The great and manifest importance, therefore, of the angle of aperture to the efficiency of the microscope, renders it indispensable that easy and practicable means should always be attainable for determining it. If the distance of the object from the object-glass, and the virtual opening or diameter of the object-glass could be always exactly measured; and if all the rays which fall on the object-glass could be assumed to pass through it, and to converge upon the image, then the angular aperture would be an element of very easy calculation. But it is not practicable to obtain these data, and it cannot be assumed that all the rays which are incident upon the object-glass will pass through it, and be made to converge upon the image.

16. Instead, therefore, of calculating the angular aperture in this manner, it is determined by immediate experiment.

The greatest angle of aperture of which a given lens is capable, will be found by determining the greatest obliquity with which it is possible for rays to fall upon the object-glass, so as to be refracted by it to the eye-glass. The following method of ascertaining this, for any given object-glass, was contrived and practised by Mr. Pritchard, at an early epoch in the progress of the improvement of the microscope, when the importance of the angular aperture was demonstrated by that eminent artist and Dr. Goring. The same method, with but little modification, is that still practised by opticians.

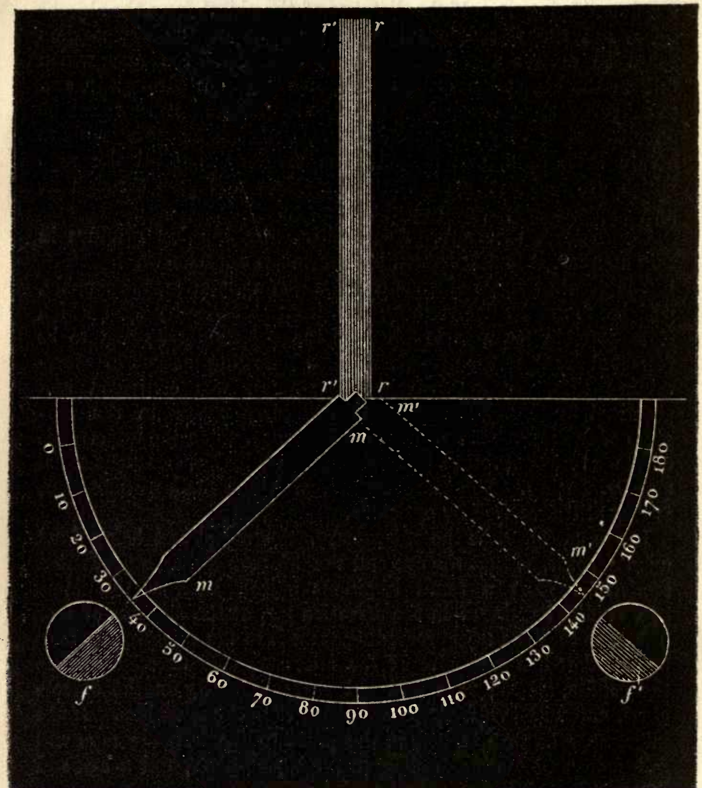
Let *m m*, fig. 9, be the microscope, the object end being fixed upon a pivot, so that the eye end can be moved over a graduated semicircle. Let a small luminous object, such as the flame of a candle, be placed in the direction *r r*, at the distance of 6 or 8 feet, so that the rays proceeding from it to the object-glass may be considered as parallel. If the microscope be directed towards the candle, all the rays will fall perpendicularly on the object-glass, and will evidently pass through it to the eye-glass. If the microscope be then turned on the pivot to the left, the rays will fall more and more obliquely on the object-glass, and a less and less number of them will pass to the eye-glass.

When such a position as *m m* is given to the microscope, those rays only which fall upon the border of the object-glass upon the right of the observer, will arrive at the eye-glass, and the field of view will then appear, as shown at *f*, half illuminated and half dark. If the microscope be moved beyond this position, the field

will be entirely dark, no rays being transmitted to the eye-glass.

If the microscope, on the contrary, be moved to the other side of the graduated semicircle, the same appearances will be produced, and when it assumes the position *m′ m′*, the field will be again half illuminated, and beyond that point it will be dark.

Fig. 9.



The arc of the graduated semicircle, included between the two positions *m m* and *m′ m′*, will then be the measure of the angular aperture of the object-glass, since that arc will correspond with the greatest obliquity, at which rays diverging from the object to

the object-glass, can pass through the latter, so as to arrive at the eye-glass.

Such are then, generally, the means by which the three conditions of distinct vision with the microscope will be fulfilled. The second of these conditions, that which involves the complete correction of the chromatic aberration, will, however, require here some further development, since it involves circumstances which have demanded the greatest artistic skill on the part of the makers.

17. It has been shown in our Tract upon "Optical Images," 53 *et seq.*, that the chromatic aberration of lenses is corrected by combining together two lenses, one of flint and one of crown glass, which have different effects upon the separation of the coloured images, the curvatures of their surfaces being so related, the one to the other, that the separation which would be produced by either is exactly counteracted by an equal separation in a contrary direction by the other. If the curvatures, however, of the two lenses be not so related as to produce this exact compensation, they may either give a predominance to the effect of the one or the other, so as to produce chromatic aberrations of opposite kinds; the coloured images thus produced being ranged in a contrary order.

When a single convex lens is used, the most refrangible rays are brought to a focus, nearer to the lens than the least refrangible; and consequently the violet and blue images are formed nearer to the lens than the red and orange. This is called POSITIVE CHROMATIC ABERRATION.

If by combining two lenses of flint and crown glass this aberration be more than compensated, that is, if the blue and violet images are not merely brought to coincide with the red and orange ones, so as to render the lens achromatic, but made to interchange place with them, so that the red and orange shall be nearest to, and the blue and violet farthest from the lens, the chromatic aberration will be NEGATIVE.

The importance of this in the practical construction of the microscope will presently appear.

It must be remembered that the microscope consists of the object-glass, the field-glass, and the eye-glass, and that its efficiency depends not merely upon the fidelity of the image produced by the object-glass, but upon that which is seen by the observer looking through the eye-glass. This last must be an exact reproduction of the object in form and colour.

Now it is easy to show that if the object-glass be absolutely achromatic, the image seen by the observer through the eye-glass will not be so; for, in that case, the rays forming the image produced by the object-glass passing successively through the field-

glass and the eye-glass, neither of which are achromatic, the image viewed by the observer through the eye-glass must be affected by as much positive aberration as is due to the combination of the field-glass and the eye-glass.

This defect might, it is true, be remedied by making both the field-glass and eye-glass achromatic; but independently of other objections to such an expedient, it would be needlessly expensive; and the same purpose is attained in a much more simple manner, upon the principles of positive and negative chromatic aberrations, which have just been explained.

The method practised for this purpose may be briefly and generally explained thus: The field-glass and the eye-glass being simple convex lenses, produce positive chromatic aberration. The object-glass, on the other hand, being a compound lens, may be so constructed, according to what has been just explained, as to produce negative chromatic aberration.

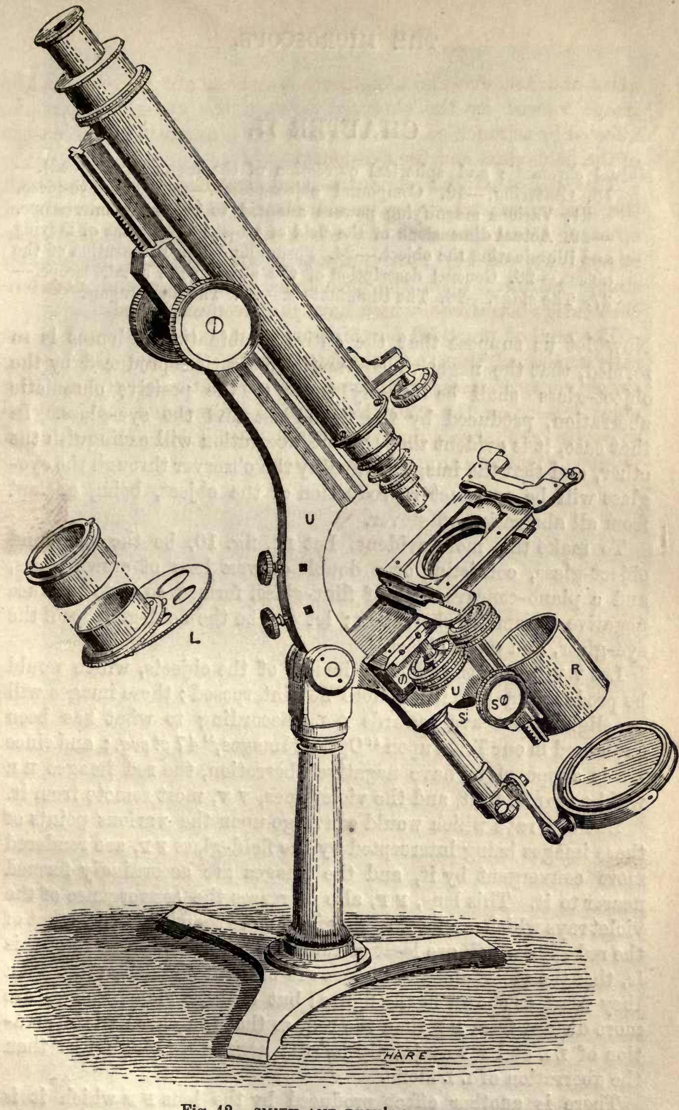


Fig. 42.—SMITH AND BECK'S MICROSCOPE.

THE MICROSCOPE.

CHAPTER II.

Mutual chromatic and spherical correction of the lenses (Continued).—18. Centering.—19. Compound object-pieces.—20. The eye-piece.—21. Various magnifying powers adapted to the same microscope.—22. Actual dimensions of the field of view.—23. Means of moving and illuminating the object.—24. Focussing.—25. Preparation of the object.—26. General description of the structure of a microscope.—27. The stage.—28. The illuminators.—29. The diaphragms.

Now let us suppose that the entire combination of lenses is so formed, that the negative chromatic aberration produced by the object-glass shall be exactly equal to the positive chromatic aberration, produced by the field-glass and the eye-glass. In that case, it is evident that the one aberration will extinguish the other, and that the image viewed by the observer through the eye-glass will be an exact reproduction of the object, being exempt from all aberration whatever.

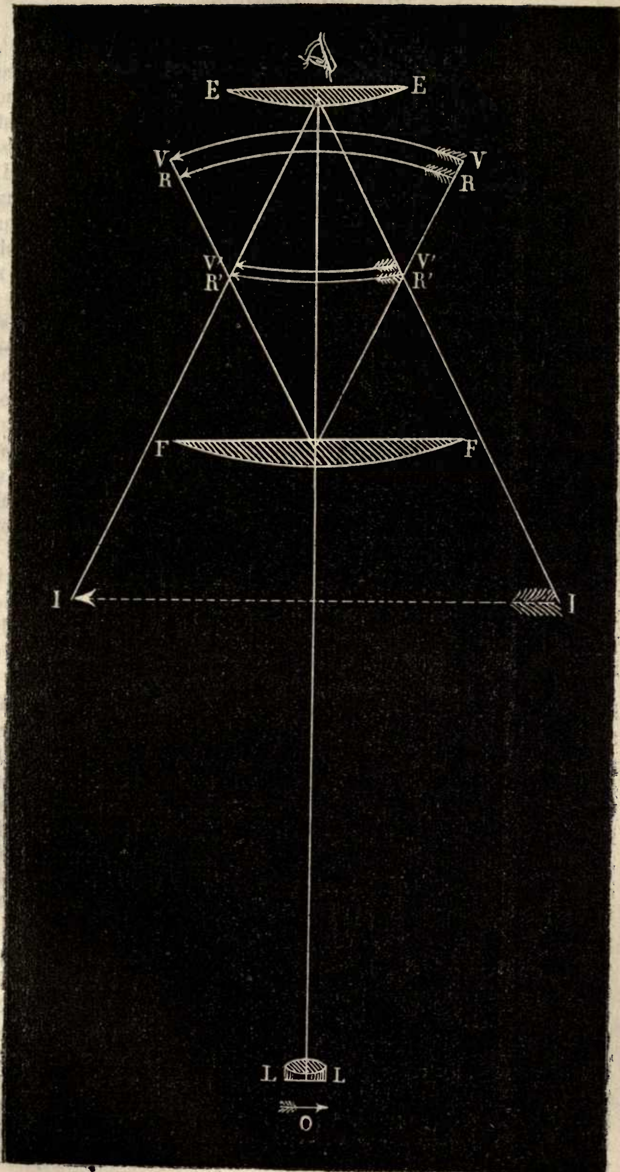
To make this more evident, Let LL, fig. 10, be the compound object-glass, consisting of a double convex lens of crown glass, and a plano-concave lens of flint-glass, formed so as to produce negative chromatic aberration; let F F be the field-glass, E E the eye-glass, and O the object.

Let V V R R be the coloured images of the objects, which would be produced by L L, if F F were not interposed; these images will be slightly concave towards L L, according to what has been explained in our Tract upon "Optical Images," 47 *et seq.*; and since L L is supposed to have negative aberration, the red images R R will be nearest to it, and the violet ones, V V, most remote from it.

But the rays which would converge upon the various points of these images being intercepted by the field-glass F F, are rendered more convergent by it, and the images are accordingly formed nearer to it. This lens, F F, also increases the convergence of the violet rays which are most refrangible, more than it increases that of the red rays which are least refrangible. The consequence of this is, that the violet and red images are brought closer together than they were, as shown in the figure; but still the violet images are more distant from F F than the red, so that the chromatic aberration of L L and F F conjointly is still negative, though less than the aberration of L L alone.

There is another effect produced by the lens F F which it is important to notice. The images produced by L L, which were slightly concave towards F F, are changed in their form, so as to be slightly concave towards E E. The cause of this change has been already explained in our Tract upon "Optical Images," 46.

Fig. 10.



In fine, then, the rays diverging from the images R′ R′ V′ V′, after passing through the eye-glass E E, have their divergence diminished, so as to diverge from more distant points, I I. The divergence of the violet rays, V′ V′, being most refrangible, is most diminished, and that of the red rays, R′ R′, being least refrangible, is least diminished. If their divergence were equally diminished, a series of coloured images would be formed at I I, the violet being nearer to, and the red farther from E E; but the divergence of the violet, which is already greater than the red, is just so much greater than the latter, that the difference of the effects of E E upon it is such as to bring the images together at I I.

Thus it appears, that the positive aberration of the eye-glass E E is exactly equal to the negative aberration of L L and F F taken conjointly, so that the one exactly neutralises the other, all the coloured images coalescing at I I, and producing an image altogether exempt from chromatic aberration.

There is another important effect produced by the eye-glass; the images R′ R′ V′ V′, which are slightly concave towards E E, are rendered straight and flat at I I; the principle upon which this change depends has been also explained in our Tract upon "Optical Images," 46.

Thus, it appears that, by this masterly combination, a multiplicity of defects, chromatic, spherical, and distortive, are made, so to speak, to extinguish each other, and to give a result, practically speaking, exempt from all optical imperfection.

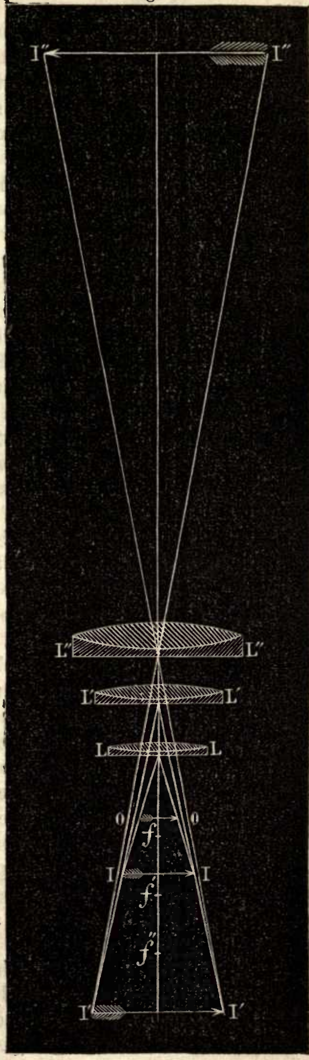
18. There is still another source of inaccuracy which, though it is more mechanical than optical, demands a passing notice. All the lenses composing the microscope require to be set in their respective tubes, so that their several axes shall be directed in the same straight line with the greatest mathematical precision. This is what is called CENTERING the lenses, and it is a process, in the case of microscopes, which demands the most masterly skill on the part of the workman. The slightest deviation from true centering would cause the images produced by the different lenses to be laterally displaced, one being thrown more or less to the right and the other to the left, or one upwards and the other downwards; and even though the aberrations should be perfectly effaced, the superposition of such displaced images would effectually destroy the efficiency of the instrument.

19. In what precedes, we have, to simplify the explanation, supposed the object-glass to consist of a single achromatic lens, a circumstance which never takes place except when very low powers are sufficient. A single lens, having a very high magnifying power, would have so short a focus and such great curvature, that it would be attended with great spherical aberration, inde-

pendently of other objections; great powers, therefore, have been obtained by combining several achromatic lenses in the same object-piece, so that the rays proceeding from the object are successively refracted by each of them, and the image submitted to the eye-glass is the result of the whole.

The optical effect of such a combination will be more clearly understood by reference to fig. 11, where L L, L′ L′, and L″ L″, represent a combination of three achromatic object-glasses. Let O O be the object, placed a little within the focus f of the lens L L. The image of O O, produced by L L, would then be an imaginary one in the position I I; (see Tract on "Optical Images," 35, *et seq.*). After passing through L L, the rays, therefore, fall upon L′ L′, as if they diverged from the several points of the image I I, which may, therefore, be considered as an object placed before the lens L′ L′. Let f' be the focus of L′ L′; the image of I I produced by L′ L′ will therefore be imaginary, and will be at I′ I′; the rays after passing through L′ L′ will fall upon L″ L″, as if they diverged from the several points of I′ I′. This image I′ I′, therefore, may be considered as an object placed before the lens L″ L″. Let f'' be the focus of this lens; the image of I′ I′ produced by L″ L″ will then be I″ I″, and will be real; this will then, in fact, be the image transmitted to the eye-piece.

Fig. 11.



To render the diagram more easy of comprehension, we have not here attempted to represent the several distances in their proper proportions.

The compound lenses, of which object-pieces consist, are generally, as represented in the figure, plane on the sides presented towards the object. This is attended, among other advantages, with that of allowing a larger angle of aperture than could be obtained if the surface presented to the rays diverging from the object were convex.

The extreme rays diverging from each point of the object fall upon the surface of the object-glass with a greater and greater obliquity as they approach its borders, and since there is an obliquity so extreme that the chief part of the rays would not enter the glass at all, but would be reflected from it, the angle of aperture must necessarily be confined within such limits, that the rays falling from the borders of the lens will not be so oblique as to come under this condition. If the surface of the object-glass presented to the object were convex, it is evident that the rays diverging from an object at a given distance from it would fall upon its borders with greater obliquity than if it were plane, and, consequently, such an object-glass would allow of a less angle of aperture than a plano-convex one with its plane side towards the object.

Improvements have recently been made in object-glasses, by which angles of aperture have been obtained so great, as not to admit even of a plane surface being presented to the diverging pencil, and it has accordingly been found necessary, in such cases, to give the object-glasses the meniscus form (Optical Images, 25), the concave side being presented to the object. By this expedient angles of aperture have been obtained so great as 170°. If the surface of the object-glass presented to the object were plane, the extreme rays of the central pencils, with such an angle of aperture, would fall upon the surface of the lens with obliquities of not more than 5°, and the obliquities of the extreme rays of the lateral pencils would be even less. Under such circumstances, the chief part of the rays near the borders of the lens would be reflected, and, consequently, its virtual would be less than its apparent angle of aperture. It is questioned by some microscopists that even with the expedient of a concave external surface, a practically available angle of aperture so great as 170° can be obtained.

The three achromatic lenses here described being mounted, so that their axes shall be precisely in the same straight line, constitute what is generally called an OBJECT-GLASS, but which, perhaps, might with more convenience and propriety be denominated an OBJECT-PIECE.

The power of the object-pieces is usually indicated by the makers, by assigning their focal lengths; but as these object-pieces are composed of several lenses, having different focal lengths, it is necessary to explain what is meant by the focal length of the combination.

Let L be a single convex lens, and O the compound object-piece; suppose then, the same object placed successively at the same distance from L and O, and let L have such a convexity that it will produce an image, I, of the object equal to the image I′, which the object-piece, O, produces, and that the distance of this image, I, from the single lens L, is equal to the distance of the image I′ from the object-piece O. In that case, the single convex lens L, being, in fact, the optical equivalent of the compound object-piece O, its focal length is taken to be that of the object-piece O. Thus, for example, if the lens L, having a focal length of one inch, produce the same image of the same object similarly placed before it, as would the object-piece O, then the focal length of the object-piece O is said to be one inch.

In short, the single lens L, and its equivalent compound object-piece O, differ only in this, that the images produced by L are defaced more or less by aberration, from which the images produced by O are altogether exempt.

These object-pieces are sold by some makers so fixed that their component lenses are inseparable, the observer being unable to use any one of them as an object-glass without the others; other makers, however, mount them in such a manner that the first and second lenses, L L and L′ L′, may be unscrewed or drawn off, and the lens L″ L″ alone used as the object-glass; or L′ L′ may be screwed on, the two lenses L′ L′ and L″ L″ then making an object-piece of greater power; by this arrangement the observer obtains, without increased expense, three object-pieces of different powers.

After what has been said, however, of the exact manner in which the aberrations of the field and eye glasses are corrected and balanced by the contrary aberration of the object-piece, it will be easily understood, that the economy by which three powers are thus obtained, is gained at the expense of the efficiency of the instrument; for if the aberrations of the triple object-piece are so adjusted as exactly to balance those of the other lenses, that balance will no longer be maintained when the lens L L, and still less when the lens L′ L′, is removed. It is on this account that some makers, who are the most scrupulous as to the character of their instruments, refuse to supply separable object-pieces.

The imperfection, however, produced in this case by disturbing the balance of the aberrations is of less importance, inasmuch as by removing the lens L L, and still more by removing L′ L′, the

magnifying power is so considerably diminished, that the defects of the image produced by the unbalanced aberrations are very inconsiderable, and the observer is generally content to tolerate them on account of the great economy gained by the separation of the lenses, which supplies, without additional expense, three independent object-pieces.

Some of the foreign makers, less scrupulous in the exact adjustment of their optical combinations, make all the three lenses composing each triple object-piece exactly similar, unscrewing one from another, so as to enable the observer to use one, two, or three at pleasure. It is evident that, with such combinations, the aberrations can never be so exactly balanced as they are in the object-pieces above described; but in the instruments to which they are applied, powers exceeding 700 or 800 are almost never attempted, and the aberrations, though imperfectly compensated, are sufficiently so to prevent much injurious confusion in the images.

In the superior class of instruments, where magnifying power is pushed to so extreme a limit as 1500 or 2000, the most extreme precision in the balance of the aberrations must necessarily be realised, since the slightest imperfection so prodigiously magnified would become injuriously apparent.

The extreme degree of perfection, which has been attained in the best class of microscopes, may be imagined, when it is stated, that an object which is distinctly visible under a power of 1500 or 2000, when it is exposed to the object-glass uncovered, will be sensibly affected by aberration if a piece of glass, no more than the 100th of an inch in thickness, be laid upon it. Infinitesimally small as is the aberration produced by such a glass film, it is sufficient, when magnified by such a power, to be perceptible, and to impair in a very sensible manner the distinctness of the image.

As it has been found necessary, for the preservation of microscopic objects, to cover them with such thin films of glass, through which, consequently, they are viewed, adjustments are provided in microscopes with which the highest class of powers are supplied, by which even the small aberration due to these thin plates of glass thus covering the objects can be corrected. This is effected by mounting the lenses, which compose the triple object-piece, in such a manner that their mutual distances, one from another, can be varied within certain small limits, by motions imparted to them by fine screws. This change of mutual distance produces a small effect upon the aberrations, rendering their total results negative to an extent equal to the small amount of positive aberration produced by the thin glass which covers the object.

20. The eye-glass and the field-glass are both plano-convex

lenses, having their plane sides turned towards the eye; they are set in opposite ends of a brass tube, varying in length from two inches downwards, according to their focal lengths, the distance between them and, consequently, the length of the tube being always equal to half the sum of their focal lengths.

The higher the power of the eye-piece, and consequently the shorter the focal length of the eye-glass, the less will be the length of the tube in which they are set.

This tube is called the EYE-PIECE.

It will be apparent from what has been explained, that the magnifying power of the instrument will depend conjointly on those of the object-piece and eye-piece.

21. In the prosecution of microscopic researches, the use of very various magnifying powers is indispensable; the higher powers would be as useless for the larger class of objects, as the lower ones for the smaller. But even for the same object, a complete analysis cannot be accomplished without the successive application of low and high powers: by low powers the observer is presented with a comprehensive view of the entire form and outline of the object under examination, just as an aëronaut who ascends to a certain altitude in the atmosphere obtains a general view of the country, which would be altogether unattainable upon the level of the ground. By applying successively higher powers, as has been already explained, the smaller parts and minuter features of the object are gradually disclosed to view, just as the aëronaut, in gradually descending from his greatest altitude, obtains a view of objects which were first lost in the distance, but at the same time loses, by too great proximity, the general outline.

The microscope-makers, therefore, supply in all cases an assortment of powers, varying from 30 or 40 upwards; observations requiring powers under 40, being more conveniently made with simple microscopes. For this purpose it is usual, with the best instruments, to furnish six or eight object-pieces and three or four eye-pieces, each eye-piece being capable of being combined with each object-piece. The number of powers thus supplied will be equal to the product of the number of object-pieces, multiplied by the number of eye-pieces.

The powers, however, may still be further varied, by provisions for changing the distance between the object and eye-pieces, within certain limits. For this purpose, the tube of the instrument is sometimes divided into two, one of which moves within the other, like the tube of a telescope, the motion being produced by a fine rack and pinion: in this case the eye-piece is inserted in one of the tubes, and the object-piece in the other. By combining

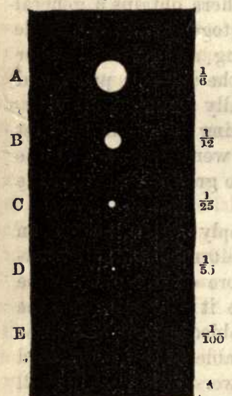
this provision with a proper assortment of object-pieces and eye-pieces, all possible gradations of power between the highest attainable, and the lowest which is applicable, can be obtained.

The actual magnitude of the space which can be presented at once to the view of the observer, will vary with the magnifying power; but in all cases it is extremely minute. Thus, with the lowest class of powers, where it is largest, it is a circular space, the diameter of which does not exceed the 8th or 10th of an inch; it follows, therefore, that no object, the extreme limits of whose linear magnitude exceed this, can be presented at once to the view of the observer. Such objects can only be seen in their ensemble, by means of less powerful magnifying glasses, or with the naked eye.

22. The field of view, with powers from 100 to 300, varies in diameter from the 15th to the 40th of an inch; from 300 to 500 it varies from the 40th to the 70th of an inch; and from 500 to 700 from the 70th to the 100th of an inch.

It will thus be understood, that even with the moderate power of 700, an object to be included wholly within the field of view, must have a magnitude such as may be included within a circle whose diameter does not exceed the 100th of an inch. These observations will be more clearly appreciated by reference to the annexed diagram, fig. 12, where A is a circle whose diameter is the 6th of an inch; B one whose diameter is the 12th of an inch; C the 25th, D the 50th, and E the 100th.

Fig. 12.



But when still higher powers are used, the actual dimensions of the entire space comprised within the field of view will be so very minute, that an object which would fill it, and still more, smaller objects included within it, would not only be altogether invisible to the naked eye, but would require considerable microscopic power to enable the observer to see them at all.

The actual dimensions of the field of view, which correspond to each magnifying power, vary more or less in different instruments. Those which I have given above, are taken from a microscope made by Charles Chevalier, which is in my possession. The difference however in this respect, between one instrument and another, is not considerable, and the above will serve as a fair illustration of the limits of the field of instruments in general.

The entire dimensions of the field of view therefore being so exceedingly minute, it will be easily understood that some difficulty will attend the process by which a small object, or any particular part of an object, can be brought within it: thus, with a moderate power of 500, the entire diameter of the field being no more than the 70th of an inch, a displacement of the object to that extent, or more, would throw it altogether out of view. If therefore the object, or whatever supports it, be moved by the fingers, the sensibility of the touch must be such as to be capable of producing a displacement thus minute.

If the object be greater in its entire dimensions than the field of view,—a circumstance which most frequently happens,—a part only of it can be exhibited at once to the observer; and to enable him to take a survey of it, it would be necessary to impart to it, or to whatever supports it, such a motion as would make it pass across the field of view, as a diorama passes before the spectators, disclosing in slow succession all its parts, and leaving it to the power of the observer to arrest its progress at any desired moment, so as to retain any particular part under observation.

The impracticability of imparting a motion so slow and regular by the immediate application of the hand to the object, or its support, will be very apparent, when it is considered that while the entire object may not exceed a small fraction, say, for example, the 20th of an inch in diameter, the entire diameter of the field of view may be as much as 20 times less, so that only a 20th part of the diameter of the object would be in any given position comprised within it.

23. These and similar circumstances have rendered it necessary that the want of sufficient sensibility and delicacy of the touch in imparting motion to the object, shall be supplied by a special mechanism, by means of which the fingers are enabled to impart to the object an infinitely slower and more regular motion, than they could give it without such an expedient. The means by which this is accomplished will be presently explained.

We have seen that the intensity with which the microscopic image is illuminated depends on the angle of aperture, other things being the same; but however large that angle may be, when considerable magnifying power is used, it is necessary that the object itself should be much more intensely illuminated than it would be by merely exposing it to the light of day, or that of the most brilliant lamp. It is therefore necessary to provide expedients, by which a far more intense light can be thrown upon it.

24. The instrument is said to be in FOCUS when the observer is enabled to see with the eye-glass the magnified image of the

object with perfect distinctness; this will take place provided the mutual distances between the eye-piece, the object-piece, and the object are suitably adjusted; and this adjustment may be accomplished by moving any one of these three towards or from the other two, while these last remain fixed: thus, for example, if the object and the object-piece remain unmoved, the instrument may be brought into focus by moving the eye-piece to or from the object-piece. The rack and pinion, already described, which moves the tube in which the eye-piece is inserted, can accomplish this. This provision, however, is not made in all microscopes.

If the eye-piece and the object be fixed, the instrument may be brought into focus by moving the object-piece to or from the object. To effect this, it would be necessary that the object-piece should be inserted in a tube, moved by a rack and pinion, like that of the eye-piece.

In fine, if the object-piece and eye-piece be both fixed, the instrument may be brought into focus by moving the object, or whatever supports it, to or from the object-glass.

All these methods are resorted to in the different forms in which microscopes are mounted by different makers.

25. Since nearly all material substances, when reduced to an extreme degree of tenuity, are more or less translucent, and since almost all microscopic objects have that degree of tenuity by reason of their minuteness, it happens that nearly all of them are more or less translucent; and where in exceptional cases a certain degree of opacity is found, it is removed without interfering with its structure, by saturating the object with certain liquids, which increase its translucency, just as oil renders paper semi-transparent. The liquid which has been found most useful for this purpose, is one called CANADA BALSAM. When the object is saturated with this liquid, it is laid upon a slip of glass, about two inches long and half an inch wide, and is covered with a small piece of very thin glass, made expressly for this purpose, the thickness in some cases not exceeding the 100th of an inch. It is usual to envelope the oblong slip of glass, in the middle of which the object is thus mounted with paper gummed round it, a small circular hole being left uncovered on both sides of the glass, in the centre of which the object lies.

The slips of glass thus prepared, with the objects mounted upon them, are called *slides* or *sliders*; and the objects thus mounted are so placed, that the axis of the object-piece shall be directed upon that part of them which is submitted to observation, provisions being made to shift the position of the slider, so as to bring all parts of the object successively under observation. Further provisions are also made to throw a light upon the

object, by which it will be seen as an object is on painted glass.

Since, however, there are some few objects which cannot be rendered translucent, expedients must be provided, by which they can be illuminated upon that side of them which is presented to the microscope. It is often necessary, also, even in the case of translucent objects, that they should be viewed by means of light thrown upon that side of them which is turned to the object-glass.

26. These general observations being premised, we shall proceed to explain the method by which the optical part of the instrument is mounted, and the several accessories by which the object is supported, moved, and illuminated.

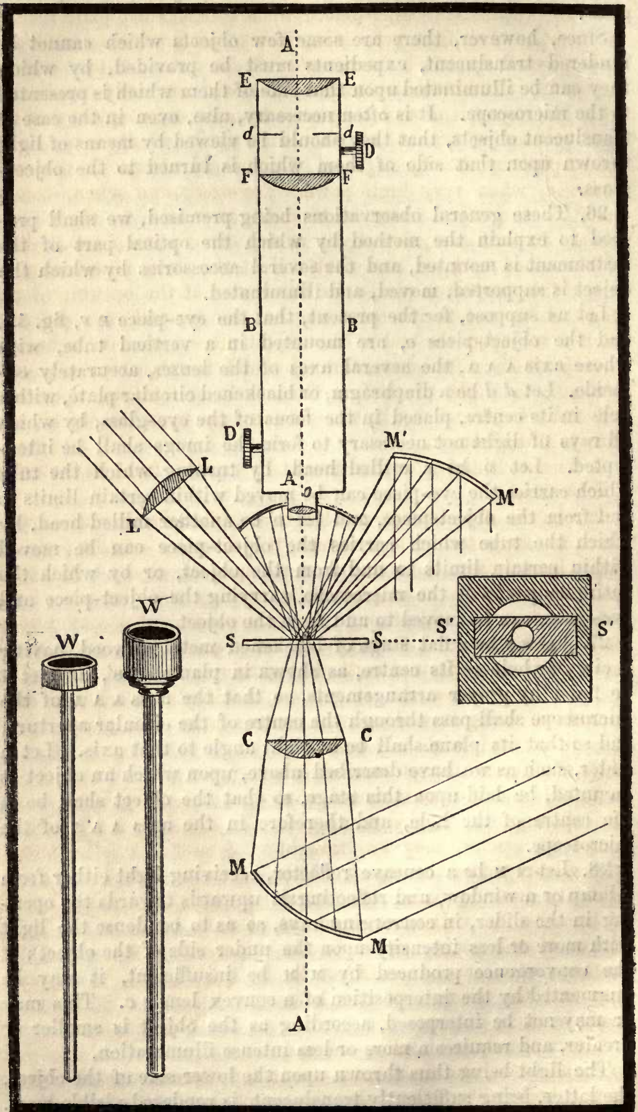
Let us suppose, for the present, that the eye-piece E F, fig. 13, and the object-piece *o*, are mounted in a vertical tube, with whose axis A A A, the several axes of the lenses, accurately coincide. Let *d d* be a diaphragm, or blackened circular plate, with a hole in its centre, placed in the focus of the eye-glass, by which all rays of light not necessary to form the image shall be intercepted. Let D be a milled head, by turning which the tube which carries the eye-piece can be moved within certain limits to and from the object-piece, and let D′ be another milled head, by which the tube which carries the object-piece can be moved within certain limits to and from the object, or by which the entire body B B of the microscope, carrying the object-piece and eye-piece, can be moved to and from the object.

27. Let S S be a flat stage of blackened metal or wood, having a circular hole in its centre, as shown in plan at S′ S′, and let it be fixed by proper arrangements, so that the axis A A A of the microscope shall pass through the centre of the circular aperture, and so that its plane shall be at right angle to that axis. Let a slider, such as we have described above, upon which an object is mounted, be laid upon this stage, so that the object shall be in the centre of the hole, and therefore in the axis A A A of the microscope.

28. Let M M be a concave reflector, receiving light either from a lamp or a window, and reflecting it upwards towards the opening in the slider, in converging rays, so as to condense the light with more or less intensity upon the under side of the object; if the convergence produced by M M be insufficient, it may be augmented by the interposition of a convex lens C C. This may or may not be interposed, according as the object is smaller or greater, and requires a more or less intense illumination.

The light being thus thrown upon the lower side of the object, the latter, being sufficiently translucent, is rendered visible by it.

Fig. 13.

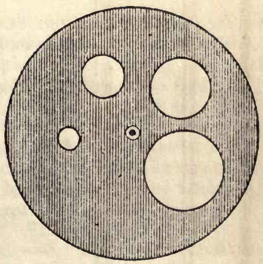


If the object be opaque, it may be illuminated from above by several expedients; being placed upon a blackened plate resting on the stage S S, light proceeding from a window or a lamp may be condensed upon it by a concave reflector M′ M′, or by a convex lens L L. These arrangements, however, are only applicable when the object is at such a distance from the object-piece that the light proceeding from M′ M′ or L L shall not be wholly or partially intercepted by the object-piece. This would always be the case, however, when very high powers are used, and when, consequently, the object must be brought very close to the object-piece. In that case, the object is supported upon a small piece of blackened cork, or in a dark cell of the form represented at W W; this support is placed in the centre of the opening of the stage, so as not to intercept any but the central rays reflected from M M; upon the end of the object-piece a concave reflector, having a hole in its centre, through which the object-piece passes, is fixed; the light proceeding from M M, and falling upon this reflector, is reflected by it, so as to converge upon the object, and thus to illuminate it.

A concave illuminator thus mounted is called, from its inventor, a *lieberkuhn*.

29. In the illumination of objects it is frequently necessary to limit, to a greater or less extent, the diameter of the pencil of light thrown from the reflector, M M, upon the object. Although this may partly be accomplished by varying the distance of the reflector from the object, or by the interposition of a convex lens, such expedients are not always the most convenient, and a much more ready and effectual method of attaining this end is supplied by providing below the stage, S S, a circular blackened disc, capable of being turned upon its centre in its own plane. This disc is pierced with a number of holes of different diameters, as shown in fig. 14, and it is so mounted, that the openings in it, by turning it round its centre, may be brought successively under the object. This is easily done by fixing the centre of this disc at a distance from the centre of the stage, equal to the distance between the centre of the disc and the centres of the holes made in it.

Fig. 14.



This appendage is called the *disc of diaphragms*, and is of great use in the illumination of objects, as will appear hereafter.

As the effect of the illuminators varies not only with their distance from the object, but also with the direction in which the light directed from them falls upon the object, provisions are made in mounting the microscope, by which various positions may be given to them, so that the light may fall upon the object in any desired manner.

In the frame in which the illuminator, M M, is mounted, it is customary to place two reflectors, one at each side, one concave and the other plane. By the former a converging, and by the latter a parallel pencil of light is reflected towards the object.

In this general illustration we have supposed the axis of the instrument to be vertical; it may, however, have any direction whatever; but whatever be its direction, the stage, S S, must always be at right angles and concentric with it. The eye-piece and object-piece are also supposed to be set in the same straight tube, with their axes set in the same straight line. This arrangement, though most commonly adopted, is neither necessarily nor always so. The tube which carries the eye-piece may, on the contrary, be inclined, at any desired angle, with that which carries the object-piece; for this purpose it is only necessary to place in the angle formed by the two tubes a reflector, so inclined that the rays coming from the object-piece shall be reflected along the axis of the tube which carries the eye-piece.

Fig. 46.—NACHET'S MULTIPLE MICROSCOPE.

THE MICROSCOPE.

CHAPTER III.

30. Oblique plane reflectors. THE SUPPORT AND MOVEMENT OF THE OBJECT: 31. The stage.—32. Mechanism for focussing.—33. Coarse adjustment.—34. Fine adjustment.—35. Method of determining the relief of an object.—36. Difficulty of bringing the object into the field.—37. Mechanism for that purpose.—38. Mechanism to make the object revolve.—39. Object to be successively viewed by increasing powers.—40. Slides to be cleaned.—41. Compressor.—42. Apparatus for applying voltaic current. THE ILLUMINATION OF OBJECTS: 43. Curious effects of light on objects.—44. Illumination by transmission and reflection.—45. Microscopic objects generally translucent, or may be made so.—46. Effects of varying thickness.—47. Varying effects of light and shade.—48. Uses of the Lieberkuhn.—49. Effects of diffraction and interference.—50. Use of daylight.—51. Artificial light.—52. Protection of the eye.—53. Pritchard's analysis of the effects of illumination.

30. Thus, for example, if the tube which carries the object-piece be vertical, a plane reflector, M M, fig. 15, receiving the rays

Fig. 15.

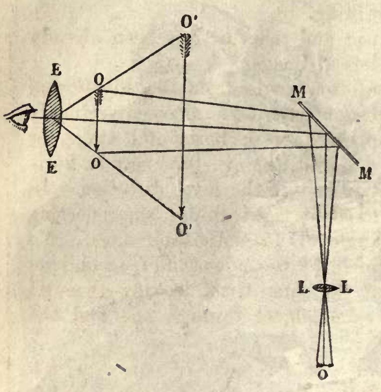
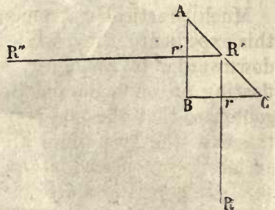


Fig. 16.



coming in a vertical direction from the object-piece, will reflect them horizontally to the eye-piece E E.

The same object would be attained with more advantage, and less loss of light, by means of a rectangular prism, A B C, fig. 16,

Fig. 17.

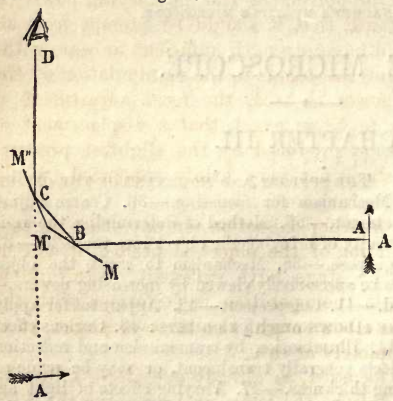
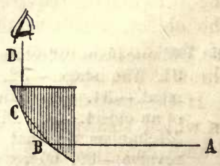


Fig. 18.



the vertical ray, R R′ being reflected by the back, A C, of the prism in the horizontal direction R′ R″.

Since a single reflection thus made produces an inverted image,

it is sometimes preferable to accomplish the object by two successive reflections, as shown in fig. 17, where the ray, A B, is successively reflected at B and C to the eye at D. And the same object may be attained more advantageously by means of a quadrangular prism, as shown in fig. 18.

This application of the prism and reflector has been already explained in our Tract upon Optical Images.

Much practical convenience often arises from the adoption of this expedient; thus, while the object-tube is directed vertically downwards, to an object supported on a horizontal stage, or floating on or swimming in a liquid, the eye-tube may be horizontal, so that the observer may look in the level direction. In this case the two tubes are fixed at right angles, the reflecting surface being placed at an angle of 45° with their axes. We shall see hereafter a case in which, by the adoption of an oblique tube, several observers may at the same time, looking through different eye-pieces, see the same object through one and the same object-glass.

THE SUPPORT AND MOVEMENT OF THE OBJECT.

31. The appendage of the microscope, adapted for the support of the object is called THE STAGE.

Since every motion or disturbance by which the stage may be affected will necessarily be increased, when seen through the microscope, in the exact proportion of the magnifying power, it is of the utmost importance that it should be exempt from all tremor, and that it should have strength sufficient to bear, without flexure, the pressure of the hands in the manipulation of the object. When a high power is used, the focal adjustment of the instrument requires to be so exact, that a displacement of the object, which would be produced by the slightest pressure of the fingers upon a stage not very firmly supported, would throw it out of focus.

If the instrument be used for dissection, or any other purpose in which steady manipulation of the object is needed, it will be found convenient that the stage have sufficient magnitude to support both wrists, while the operation is performed with the fingers. Supports for the elbows ought also to be arranged, so as to place the operator completely at ease.

32. The instrument is focussed, as already explained, either by moving the stage to and from the body, or by moving the body to and from the stage. The motion is imparted to the one or the other by means of a milled head placed on the right of the observer, which leaves a pinion working in a rack to which the

part to be moved is attached. By turning this milled head one way and the other alternately, the observer finds by trial the position which gives greatest distinctness.

33. This, which is called the COARSE ADJUSTMENT, answers well enough when high powers are not used; but it must be remembered that as the teeth of the pinion successively pass those of the rack, the motion produced is not strictly an even and uniform one, but a sort of starting or intermitting motion, so that the instrument cannot be easily and steadily brought to rest at any intermediate point between the beginning and the end of the passage of a tooth. When high powers are used, and consequently an extremely nice adjustment of the focus required, this arrangement is therefore insufficient, and serves at best only for a first approximation to the exact focus.

34. A supplemental expedient is therefore provided in the best instruments, called the FINE ADJUSTMENT, which usually consists of a screw having an extremely fine thread, which being connected with the part to be moved, gives it a perfectly smooth, uniform, and slow motion, entirely free from starts or jerks.

In some of the best instruments these screws have as many as 150 threads to the inch, so that one complete turn of the milled head moves the stage or body through only the 150th part of an inch, and as the head is divided into ten equal parts and moves under an index, a tenth of a revolution can be observed, which corresponds to the 1500th part of an inch.

When the form of the object is not actually flat, and consequently all points upon it are not equally distant from the object-glass, they will not be all in focus together. When the distance of the object is such as to bring the more salient, and consequently the nearest, parts into focus, the more depressed parts will be too distant and consequently out of focus; and when the object is moved nearer to the object-glass by a space equal to the heights of the salient above the depressed parts, the latter will be in, and the former out of focus, and consequently the latter will be distinct, and the former confused.

When the powers used are so low that the distance of the object from the object-piece shall bear a considerable proportion to the difference of level of the salient and depressed parts of the object, this difference of level will not sensibly affect the focal adjustment; but when high powers are used, that difference of level bearing a very sensible proportion to the distance of the object from the object-glass, the adjustment which renders either distinct will render the other indistinct.

35. This optical fact has been converted with admirable address

into an expedient, by which the inequalities of the surface of a microscopic object are gauged, and its accidents analysed. Thus, for example, let the milled head of the fine adjustment be first turned so as to render the salient parts distinct, and let the position of the index be marked. Let it be then turned so as to render the depressed parts distinct, and let the new position of the index be marked. If one division of the head represent the 1500th part of an inch, the differences of level, of the salient and oppressed parts, will be just so many 1500ths of an inch as there are divisions of the milled head which have passed the index.

36. One of the first difficulties which the microscopic debutant encounters, is that which will attend his attempts to bring the object into the centre of the field of view when it is minute, and when the magnifying power is considerable. If he is only provided with a simple stage, without any mechanical expedient for moving the object, he will soon be oppressed with the fatigue arising from a succession of abortive attempts at accomplishing his purpose.

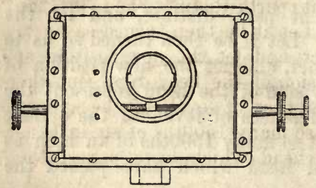
37. The entire diameter of the field of view will often be less than the 100th of an inch, so that a displacement of the slide so inconsiderable as to be utterly insensible to his fingers, will cause the object to jerk through a space greatly exceeding the entire extent of the field. In this way the object will start from side to side, the motion imparted to it by the touch to bring it back to the field being always in excess, however carefully and delicately the manipulation may be made. Some professional observers, by intense and long-continued practice, surmount this difficulty and succeed in adjusting the slides, even with the highest powers, without mechanical aid; but this is not to be hoped for by debutants or amateurs, except with very low magnifying powers. Such persons, if they would avoid the risk of throwing up the instrument with disgust, had therefore better in all cases be provided with a stage having some such expedients as we shall now describe.

Upon the fixed stage, such as it has been described, a second stage similar in form and equal in size is placed, and is moveable through a certain limited space right and left, by a fine screw with a milled head. Another similar stage is placed upon this, which partakes of any motion imparted to the latter, but which is also moveable upon the latter backwards and forwards by means of another fine screw. Upon this last stage the slide with the object is placed, and held down by springs so as to retain its place, whatever be the position of the stage.

By turning one of these screws (fig. 19), the object may be

slowly moved right and left, and by turning the other it may be moved backwards and forwards, and, in fine, by turning both at the same time it may be moved diagonally in any intermediate direction, according to the relative rate at which the one and the other milled head is turned. Sometimes the two milled heads are on the right side of the stage, so that they can be turned either separately or together by the right hand, and sometimes they are placed at opposite sides, so as to engage both hands.

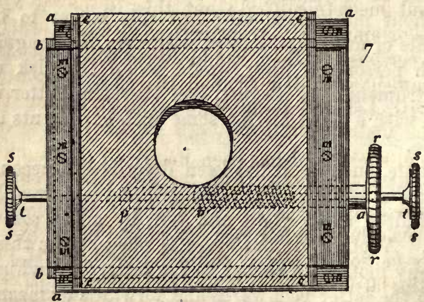
Fig. 19.



38. It is generally found convenient to have an easy means of turning the object round its centre, so as to present it to the light in all possible positions, without displacing it from the centre of the field. This is accomplished by inserting in the upper plate of the stage a metallic disc of somewhat greater diameter than the central aperture of the stage, which is so fixed as to be turned smoothly round its centre. It is upon this disc that the slide is placed and held by the springs which are attached to the disc so as to turn with it. This disc is sometimes graduated in 360°, so that the observer can turn the object through any desired angle, a power which will be found very convenient in certain classes of observations.

The arrangement consisting of a fixed with two moveable stages superposed is drawn in fig. 20, where *a a a a* is the fixed stage, and *b b b b*, *c c c c* the two stages which move in the grooves *n n* and *m m*, the one *b b b b* directed right and left, and the other *c c c c* backwards and forwards. The grooves in which the upper stage *c c c c* moves are formed in the lower stage *b b b b*, and those in which the latter moves are formed in the fixed stage *a a a a*. The one stage is moved by turning the milled heads *s s* fixed upon the

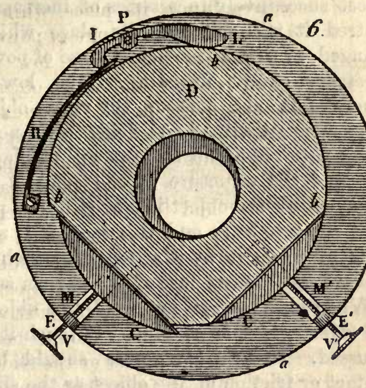
Fig. 20.



rod $t\,t$, and the other by turning the head $r\,r$ fixed upon the hollow rod v, through which $t\,t$ passes.

Another and more simple form of moveable stage is shown in fig. 21, where *a a a* represents a circular brass disc, having a circular aperture in its centre. Upon this a second disc *b b b* is placed, which is moved within certain limits in two directions, at right angles to each other, by the screws V V′, against which the spring R I P L reacts. The entire stage is in this case moveable round its own centre.

Fig. 21.



By these expedients the observer has complete command over the object, so as to be able to move it at pleasure in any direction, with a motion which will be smooth, slow, and free from jerks and starts, even when magnified with the highest powers.

To centre the object, that is, to place it on the stage so that its centre shall be in the centre of the field, is not so easy as it might appear to the unpractised in microscopic manipulation. To accomplish this, let the slide be first laid across the aperture of the stage, the object being as nearly as possible concentric with the aperture. Let the stage and object-glass be brought nearly, but not actually, into contact by the coarse adjustment. Let the slide be then again centred, so as to render the object concentric with the object-glass. Let the stage be then moved from the object-glass until the instrument is focussed as nearly as it can be by the coarse adjustment. Let the object be then more exactly centred by the stage-screws, and more exactly focussed by the fine adjustment.

It must not, however, be supposed that this elaborate process is necessary in the case of every class of objects. The larger sort can be easily enough centred by the hand, and focussed by the coarse adjustment; and in the cheaper description of microscopes no other means are provided. For a smaller sort, the centring may be effected by proximity with the object-glass, and rendered more exact with the fingers when no stage-screws are provided.

But much trouble will be produced when objects of the smallest class requiring the higher powers are examined with instruments in which the stage-screws and fine adjustments are not supplied.

39. In all cases it will be found advantageous to submit the object successively to a series of increasing powers. When once centred it will maintain its place while the object-lenses are changed, so that upon each change of power no new adjustment is necessary except focussing. The low powers will show the general form and contour, the entire object being at one and the same moment within the field. The next powers will show the larger parts, and the highest will display the texture of the surface and the structure of the smaller parts. By working the stage-screws the object is moved like a panorama across the field from right to left; and this motion is repeated for various positions given to it by the screws, which move it backward and forward until every part of it has been submitted to examination.

When high powers are used the object will be very close to the object-glass, so as almost to touch it when the instrument is focussed. In this case, care should be taken to prevent all contact or friction of the object or the slide with the object-glass, the latter being subject from that cause to injury or fracture. When it is desired therefore to change an object thus viewed with a high power, it is always advisable to separate the object-glass and stage by the coarse adjustment, before removing the one object and replacing it with the other, which must then be focussed.

40. The greatest care should be taken to clean the slides before placing them on the stage, since the least particle of grease or dust or any other foreign matter would, when magnified, injure the observation and might lead to errors.

When the object observed is in a drop of water or other liquid, or when it is itself a liquid, it will be included between the slide and a thin glass placed upon it, in which case it is of the greatest importance to exclude or remove all bubbles of air, since they would present appearances under the microscope, such as would deface those of the proper object of observation.

41. When it is required to submit a minute object to inspection, it is sometimes desirable to submit it to pressure, either to retain it in one position, if it be living, or to ascertain the effect of compression upon it, exercised in a greater or less degree for other purposes. It is often necessary also to roll it over, so as to present all sides of it in succession to the observer.

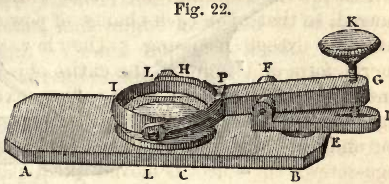
An instrument called a *compressor* has been contrived for this purpose, which has been constructed in a great variety of forms

by different makers, according to the demands of different observers.

One of the most common and useful forms of compressor is shown in fig. 22.

A small and very thin disc of glass is set in a brass ring I, and supported at two points L L, diametrically opposite, by the ends of a fork L P, attached to a lever P G, the latter being supported upon two upright pieces F, attached to an horizontal piece F D. This piece F D turns horizontally round a pivot, fixed near the end E of a strong slip of brass A B, having the form and magnitude of a slide used for the support of objects. At the middle C, of A B, is a circular hole, in which another disc of glass is set, corresponding in magnitude to the disc I. A screw, with a milled head K, works in the end G of the lever, by turning which in one way or the other, the end G, and consequently the disc I, is raised or depressed.

Fig. 22.



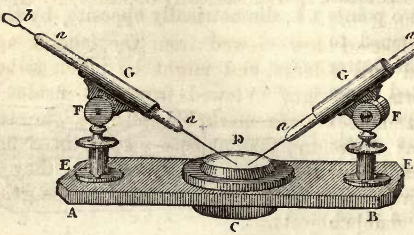
To place the object for observation, by moving the piece D round the pivot the ring I is removed from the lower disc C, upon which the object is then deposited. The screw K being turned, so as to raise the disc I sufficiently to prevent it from touching the object, the piece D is then turned on the pivot until the disc I is brought over the object. The observer then viewing the object in the microscope, and placing his hand upon the screw K, slowly turns it, so as gradually to compress the object, and continues this process or suspends it, or turns the disc I horizontally, so as to roll the object between the glasses, according as his course of observation may require.

The compression may be so increased as to flatten the object, which in some cases is desired, so as to render it more transparent, while nevertheless its form becomes more or less distorted.

42. It is sometimes required to ascertain the effects of an electric spark or voltaic current, transmitted through a liquid or solid, or through a body animate or inanimate. An apparatus adapted for this purpose is shown in fig. 23, where D C is a disc of glass set in the middle of a slip of brass A B. The two brass tubes G G play upon the hinges F F, which are supported on short glass pillars E E. Two glass tubes, through the bores of which fine platinum wires *a a* pass, are inserted tightly into the tubes G G, so that they can be pushed to, or drawn from the disc D,

where the object is placed. The positive and negative ends of the conductor of the electric machine, or the poles of a voltaic battery, being put in connection with the handles *b b* of the

Fig. 23.



platinum wire, the spark or current will pass from the point of one of the wires *a a* to that of the other, being transmitted through the object placed between them.

THE ILLUMINATION OF OBJECTS.

43. Among the accessories of the microscope, there is none the right use of which is more important than the illuminators. By the proper application of these, an infinite variety of beautiful effects are produced, and an infinite number of interesting consequences developed, while by their abuse, and by the misconception and misinterpretation of their indications, the most fatal errors and illusions may arise.

Let any one, however inexperienced in the manipulations of a microscope, applying one hand to the mirror and the other to the disc of diaphragms, vary at pleasure the position of the former, and turn the latter slowly round its centre, thus shifting the direction, and varying the quantity of the light which falls upon the object, and he will witness, in looking at the object through the instrument, a series of appearances which will soon demonstrate to him how curious, complicated, and important a part the illuminators play in microscopical phenomena.

44. Objects may be rendered visible in two ways, either by light reflected from those parts of their surfaces which are presented towards the observer, or by light falling on the posterior surface, and partially transmitted through them. Opaque bodies can be seen only in the former way, but translucent objects may be seen in either of these ways.

A translucent object presents a different appearance, according as it is seen by a front or back light. The leaf of a tree or plant, seen by reflected light, appears to have some particular tint of

green, showing faint traces of a certain reticulated skeleton of vegetable fibre. If it be held up before the sun, all light being excluded from the side presented to the eye, it will appear with a much paler tint of green, and the skeleton will become much more visible, the finer parts before invisible being distinctly seen.

A stained glass-window viewed from the outside appears to have dark and dull colours, and might be taken to be opaque, showing no form or design. Viewed from the inside, forms of great beauty, and colours of remarkable splendour, are seen.

When we say, therefore, that objects viewed in a microscope present very different appearances, according as they are illuminated by a front or a back light, we only state a general fact common to all visible objects.

No body can be said to be either opaque or transparent in an absolute sense. Bodies considered to be the most opaque, such as the metals, are found to be translucent when reduced to thin leaves. Even gold and platinum, the most dense of the metals, are rendered translucent under the hammer of the gold-beater, while glass, diamond, air, water, and similar bodies, commonly considered to be transparent, are proved to absorb a portion of the light transmitted through them, this absorption increasing with the thickness of the medium. There is in fine no body which will not become opaque if sufficiently thick, and none that will not become more or less translucent if sufficiently thin.

45. Since microscopic objects are generally of extremely minute dimensions, they are all, with some few exceptions, sufficiently translucent to be rendered visible by a back light.

It is well known that many bodies, which are opaque or nearly so, may be rendered translucent by saturating them with certain liquids. Thus, as every one knows, paper, linen, and other porous bodies, which when dry are imperfectly translucent, become much more so when wetted or oiled, or saturated with white wax.

This general physical fact has special and important application in the preparation of microscopic objects, which are saturated with various liquids, proper for each of them, by which they are rendered translucent.

When a translucent object is rendered visible by a back light, the intensity of the light must be regulated according to its translucency. The more translucent it is, the less intense must be the light. A strong back light thrown upon a very translucent object drowns it, and renders it altogether invisible. The light must therefore be reduced in intensity by varying the inclination of the reflector, the distance of the lamp from it, and by

the interposition of smaller diaphragms, until the best effect is produced. The observer will acquire by practice a facility in making these adjustments, so as to produce the desired result.

On the other hand, if the object be very imperfectly translucent, the light thrown upon it must be rendered as intense as possible by the contrary arrangements.

46. Different parts of the same object will generally have different degrees of translucency, and it will often happen that a light which would drown the more transparent parts will be no more than sufficient to display the more opaque parts. In such cases the observer will have to vary the light according as his attention is directed to one part or the other.

It must not be inferred that the darker parts are in this case really darker than those which are more transparent. The lesser degree of translucency more frequently arises from the different thickness of different parts of the object, the thicker parts absorbing more light, and therefore appearing of a darker tint than the thinner. If the varying transparency arise from this cause, the apparent lights and shadows or tints of colour must be taken as mere indications of the inequalities of thickness of a body of which the real colour is uniform.

The difficulty which an observer encounters in ascertaining the real form of an object, and the accidents of its surface when seen in a microscope by a back light, is partly owing to the fact that the eye is habituated to view objects almost exclusively by front lights, and the impressions produced of their forms are always deductions of which we are rendered unconscious by habit, by which the characters of these surfaces are inferred from the lights and shadows which are impressed on the organ of vision. Not having the same habit of seeing objects by a back light we cannot so easily make similar deductions, and we are apt to judge of the objects as if in fact they were illuminated with a front light.

The judgment is also more or less perplexed, and deceived by the fact that microscopic objects are as it were placed before the eye in an unnatural state of proximity, which give them a visual character totally different from that which objects have, viewed in the usual way with the naked eye.

It must be evident, therefore, how much attention and address on the part of the observer are indispensable to enable him to disentangle their physical causes from such complicated effects, and to give their appearances a right interpretation.

47. If an object, of which the surface is marked by numerous inequalities and asperities, be illuminated by a light which falls perpendicularly upon it, or which is scattered indifferently in all directions, an observer placed directly over it will be in general

unable to perceive the elevations or depressions, all being projected upon the same ground-plan, and all being similarly illuminated. But if the light fall upon it with a certain and regular obliquity, lights and shadows will be produced which will enable him to infer the accidents of the surface and the real form of the object.

The due consideration and application of this general optical fact will enable the microscopic observer to submit the object of his inquiry to such a visual analysis as will unfold at least a close approximation to its real form.

48. If the object be viewed by a front light proceeding from the concave mirror M M, fig. 13, or reflected by the Lieberkuhn, this effect will not be produced; for although the light reflected from the Lieberkuhn is not perpendicular to the object, it is scattered in all possible directions, so as utterly to remove all possibility of lights and shadows. An expedient is sometimes adopted in which light projected by a concave mirror or lens, properly placed, is directed only on one side of the Lieberkuhn, which is necessarily productive of lights and shadows.

But the purpose is much more simply and effectually attained by removing the Lieberkuhn altogether, and directing the illumination with the necessary obliquity upon the object by means of a reflector or lens placed as shown at M′ M′ or L L.

Those methods are always practicable except when a magnifying power is used so high as to render it necessary to bring the object almost into contact with the object-glass, in which case the mounting of the latter would intercept the light, whether proceeding from the Lieberkuhn, the lens, or mirror. In such cases the object can only be illuminated by a back light.

If the object be illuminated by a back light thrown obliquely upon it, the lights and shadows, strictly speaking, can only be produced upon the posterior surface. Nevertheless, the light passing obliquely through the anterior surface will produce dark and light tints, according to the angle at which it strikes the several superficial inequalities and accidents of that side of the object. It will be evident, therefore, that very complicated effects, in which the disentanglement of the forms which produce them is extremely difficult, must ensue.

Nevertheless, the attentive and practised observer, by presenting the illumination successively in various directions, by properly varying its intensity, and examining the object as well by front as by back illumination, when both are practicable, can generally arrive at a pretty clear knowledge of its form and parts.

49. When the object is illuminated by a back light, optical phenomena, called diffraction and interference, are produced,

against which the observer must be on his guard. The effects of these are to surround the outline of the object with coloured fringes. By limiting the illumination as far as it is practicable to the object itself, so as to avoid the transmission of any light through the opening of the slide, except what may pass through the object, this effect may be diminished or avoided.

Indeed, for many reasons, it is advantageous to prevent any light from passing through the slide, or through the opening of the stage, except what is employed in illuminating the object. All such light is liable to fall in greater or less quantity upon the object-glass, and, passing through it, has a tendency to render the image obscure and confused. For this reason, all extraneous light whatever should be as far as possible excluded from the space around the microscope, for all objects on which such light falls will reflect a part of it, some of which may fall upon the object-glass.

50. When the light of the sky or clouds is used, an aperture may be made in a window-shutter for its admission, all the other windows of the room being closed, and the light proceeding from the aperture being received upon the mirror or lens, by which it is directed and condensed upon the object. The light of a white cloud, strongly illuminated by the sun, is generally considered the best form of day-light which can be used, and that of a blue serene sky the worst. Observers differ as to the direct light of the sun, some maintaining that in no case whatever should it be used, while others give it a preference for minute objects seen under high powers, and therefore requiring intense illumination.

The light reflected from a white wall upon which the sun shines is a good source of illumination.

51. If artificial light be used with low powers, a common sperm candle will serve well enough, but means should be adopted to prevent the flickering of the flame.

An argand lamp, however, is, in all cases, preferable, as giving a steady invariable light. It will be improved if good olive oil be used instead of the fish oil.

The flame produced by the liquid known as camphine is especially pure and white, and well fitted for microscopic researches.

Whatever be the artificial light used, it ought to be surrounded with a shade, and so placed as to fall only upon the mirror or lens by which it is directed to and condensed upon the object.

52. It is advantageous to protect the eyes of the observer from extraneous light: the most simple and convenient method of effecting which is by a circular blackened pasteboard screen

about a foot in diameter, having a hole in its centre, through which the tube of the eye-piece is passed. This screen is then at right angles to the axis of the body of the instrument, the eye-piece projecting about an inch from it. The observer looking into the eye-glass with one eye, need not incur the exertion and fatigue of closing the other, since the screen performs the office of the eye-lid.

The mirrors are sometimes made with a concave glass at one side, and a plane glass at the other, the latter being used when condensation is not required. A disc formed of plaster of Paris, reduced to an extremely even and smooth surface, either plane or concave, is sometimes used with advantage when a soft and mild light is required. Nearly the same effect may be produced by placing a disc of white card upon the face of the mirror. The illumination by a back light is attended with a peculiar advantage, inasmuch as it displays the internal structure of objects, and, in the case of organised bodies, supplies beautiful means of exhibiting the circulation; as, for example, the circulation of the blood in animals, and the sap in vegetables. In the case of certain animalcules, it shows some living and moving within the bodies of others.

53. The following observations of Mr. Pritchard are worthy of attention:—"We must consider that in all bodies viewed by intercepted light, there is, properly speaking, neither light nor shade, in the ordinary acceptation of these terms; there are only dark and light parts, which again assume new aspects as the light is more or less direct or oblique. Thus depressions on transparent objects are almost sure, under the action of oblique light, to assume the effect of prominences; but prominences seldom or never have the semblance of depression. As almost all diaphanous bodies can be examined as opaque objects, a scrutiny of them in this way will generally be found greatly to assist our judgment concerning their nature, whether they admit of being cut into sections or not. It would be easy to write a volume on this subject only, if we commenced an illustration of particulars which could not be rendered clear and satisfactory without a vast number of figures. Long practice must, after all, determine our opinions, and scepticism should ever form a leading feature in them; we should *suspect rather than believe.*

"Opaque objects are not, upon the whole, so liable to produce optical deceptions as transparent ones, because we are more in the habit of viewing ordinary bodies by reflected or radiated light. The most common illusion presented by them is that of showing a *basso-relievo* as an *alto-relievo;* the reverse deception sometimes occurs also, but more rarely. This effect occurs in ordinary objects

viewed by the naked eyes, as well as in microscopes, especially if but one eye is employed. Thus, if we look intently for some time at a basso-relievo (a die of a coin, for example), *illuminated with very oblique light*, it at first appears in its true character; but, after a little while, some point on which we more particularly direct our gaze will begin to appear in *alt*, the whole rapidly follows; in a little time the effect wears off, and we again see it in bas-relief; then again in alt; and so on, by successive fits. This deception arises from the simple circumstance that *the lights and shades in bas-relief are very nearly like those of an alto-relievo of the same subject, illuminated from the opposite side;* our understanding in this case instantly corrects the false testimony of the eye, when we *consider from which side the light comes.* (If we observe with a microscope, we must remember that its image is inverted, and that in consequence the light must be considered as proceeding from the side of the field of view opposite to that where the source of illumination actually exists.) It will also be highly advisable, when we are in doubt as to the manner in which an instrument shows prominences and depressions, to verify its vision by observing some *known object* with it, of the real state of which, as to inequality of surface, we have been previously informed by the sense of touch, to which it has been well said there is no fellow." *

* "We usually see objects illuminated from *above* with the *shadows below* the prominences; now, unless the light is below an opaque object, when we view it in an engiscope, we shall see the *shadows above*, giving the prominences the appearance of depressions, and producing a very unnatural effect."

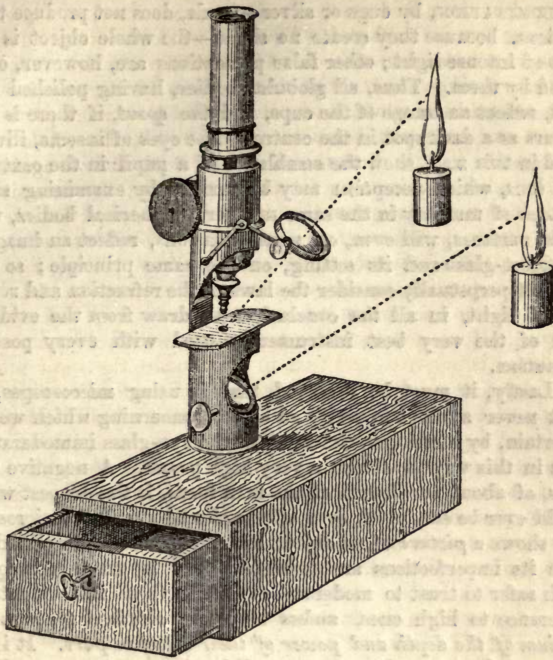


Fig. 36.—FRAUENHOFFER'S MICROSCOPE.

THE MICROSCOPE.

CHAPTER IV.

Pritchard's analysis of the effects of illumination (continued). MEASUREMENT OF OBJECTS: 54. Measurement distinct from magnifying power.—55. Measurement by comparison with a known object.—56. Micrometric scales.—57. Thin glass plates.—58. Micrometers.—59. Le Baillif's micrometer.—60. Jackson's micrometer.—61. Measurement by the camera lucida.—62. Goniometers. MAGNIFYING POWER: 63. This term much misunderstood.—64. Its exact meaning.—65. Least distance of distinct vision.—66. Visual estimate of angular magnitude.—67. Method of determining magnifying power by the camera lucida.—68. Dimensions of the least object which a given power can render visible.

"ILLUMINATION, by cups or silver specula, does not produce these illusions, because they create no shade—the whole object is one mass of intense light; other false perceptions are, however, occasioned by them. Thus, all globular bodies, having polished surfaces, reflect an image of the cups, and the *spout*, if there is one, appears as a dark spot in the centre. The eyes of insects, illuminated in this way, show the semblance of a pupil in the centre of each lens, which deception may be verified by examining small globules of mercury in the same manner. Spherical bodies, with bright surfaces, will even, on some occasions, reflect an image of the object-glass and its setting, on the same principle; so that we must perpetually consider the laws of the refraction and reflection of light, in all the conclusions we draw from the evidence even of the very best instruments, used with every possible precaution.

"Lastly, it must be observed, that in using microscopes, we must never attempt to verify an object concerning which we are uncertain, by increasing the depth of the eye-glass immoderately, so as in this way to obtain a very high power. A negative eye-glass, of about one-fourth of an inch focus, is the deepest which should ever be employed, even with a short body; for a microscope only shows a *picture* of an object, and the more it is amplified the more its imperfections are developed. It is, on this account, much safer to trust to moderate powers in these instruments, in preference to high ones, *unless they are obtained through the medium of the depth and power of their objective part.* It is the nature of deep eye-pieces to cause all luminous points to swell out into discs, and to render the image soft, diluted, and nebulous, at length all certain vision fades away, and the imagination is left to its uncontrolled operation. Single and compound magnifiers, having to deal with the real object, may be made of any power which can be used; and if our eyes are strong, and habituated to their use, we may place great reliance on their testimony; but we must never allow them to persuade us to believe marvels which are manifestly impossible, or contrary to the known laws of nature and right reason."

MEASUREMENT OF OBJECTS.

54. The determination of the real magnitude of microscopic objects, and that of the magnifying power of the instrument, are problems closely connected but not identical. Either may be solved independently of the other.

55. If two objects be placed at the same time within the field of view, the real magnitude of one of which is known, that of the other may be at least approximately estimated by comparison.

Since they are equally magnified, their real will be in the proportion of their apparent magnitudes. If, therefore, they appear equal, they will be equal, and if that which we desire to measure appear to be twice or half the size of that whose magnitude we know, its real magnitude will be twice or half that of the latter.

Such was the micrometric method used by the earlier observers. Thus Lewenhoeck procured a number of minute grains of sand, sensibly equal in magnitude, and placing as many of them in a line, and in contact, as extended over the length of an inch, he ascertained the fraction of an inch, which expressed the diameter of each. When he desired to ascertain the actual magnitude of an object seen with his microscope, he placed one of these grains beside it, and estimated by comparison the magnitude of the former.

Various natural objects, whose magnitudes are known, and which are subject to no perceptible variations, such as the sporules of Lycoperdon bovista or puff-ball, whose diameter is the 8500th of an inch, those of the lycopodium, which measures the 940th of an inch, and others such as hair, the filaments of silk, flax, and cotton, and the globules of blood, have been suggested as standard measures to be similarly used.

More modern observers, adhering to the same method, have substituted artificial for natural standards. Thus extremely fine wire, called micrometric wire, has been used. This wire can be drawn with an astonishing degree of fineness. Dr. Wollaston invented a process by which platinum wire was produced, whose thickness was only the 30000th part of an inch.*

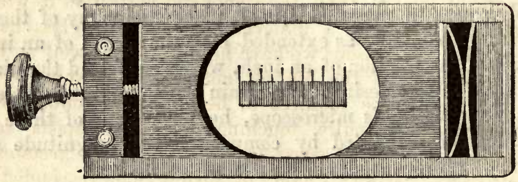
56. Such measurements are now more generally made by means of a minute scale engraved on glass, with a diamond point. Let us suppose, for example, a line, the 20th of an inch in length, traced across the centre of a glass disc, set in a thin brass plate of the size and form of the sliders on which objects are mounted. Let this line be divided into 100 equal parts, every fifth division being distinguished by a longer line, and every tenth by a still longer one. Each of these divisions will be the 2000th part, the intervals between the fifth divisions will be 400th, and that between the tenth divisions the 200th part of an inch. This microscopic scale will be seen magnified with the microscope, and any microscopic object laid upon it will be seen equally magnified, so that its dimensions can be ascertained by merely counting the divisions of the scale included between those which mark its limits when placed in different positions on the scale.

It may perhaps be thought impracticable to make divisions so

* Handbook of Natural Philosophy, 2d edition, Mechanics, 38.

minute upon the glass, with the necessary precision, especially when it is remembered that any error or inequality will necessarily be augmented in the exact proportion of the magnifying power with which such a scale is seen. Nevertheless this difficulty has been most successfully overcome, and combinations of screws and

Fig. 24.



wheels have been contrived, by which the diamond point is moved by self-acting mechanism, so as to trace the successive divisions of scales of astonishing minuteness. Scales are thus produced, the divisions of which are no greater than the 25000th part of an inch.

This extreme minuteness is, however, rarely necessary or desirable in microscopic researches, and the divisions of the scales in more common use vary from the 1000th to the 2000th of an inch. In the scales delivered with moderately good French instruments, a millimetre is divided into one hundred parts. A millimetre being about the 25th of an inch, these divisions would therefore be the 2500th of an inch. (See Tract on Microscopic Drawing and Engraving, Museum, vol. vi.)

The process described above, in which the object is measured by superposition upon the micrometric scale, is attended with several practical difficulties and objections. The object, when thus placed, is always nearer to the object-glass than the scale, and when it is in focus, the scale is out of focus and invisible; and, on the other hand, when the scale is in focus, the object is out of focus and indistinct. When low powers only are used, this difference between the focus of the object and that of the scale being inconsiderable, will not prevent the success of the operation; but when the powers are high, it can never be satisfactorily, and sometimes not at all effected.

There is still another objection to the process. The placing and displacing of objects frequently on a surface so delicately engraved, subjects it to friction, which soon spoils and effaces the divisions.

If the divided surface be protected, as it may be, by a plate of glass laid upon it, the difference between the distances of the object and the scale from the object-glass is augmented by the

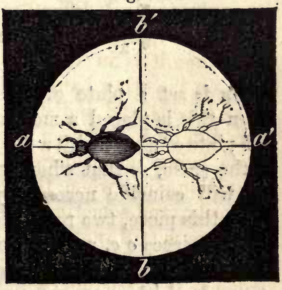
thickness of the glass which covers the scale; and however thin this glass may be, where high powers are used, it will render the difference of the foci of the scale and the object so sensible, that they can never be both seen with sufficient distinctness at the same time.

57. We know no greater example of the inexhaustible resources of art, and the untiring zeal with which its cultivators minister to the wants of science, than the wonderful perfection to which the mechanical division of a material so fragile as glass has been carried. For the reasons we have here stated, as well as because in the application of the highest magnifying powers the object-glass of a microscope requires to be almost in contact with the object, without actually touching it, microscopists required extremely thin plates of glass to cover delicate objects mounted on their slides. Messrs. Chance of Birmingham responded to this demand by the production of plates of glass so thin, that three hundred of them piled one upon the other are no higher than an inch.

For examples still more striking of the minuteness with which lines may be traced upon glass by mere mechanical processes, we may refer the reader to that part of our Tract upon Microscopic Drawing and Engraving, in which the test plates of Mr. Nobert are described.

58. One of the most evident expedients for the measurement of microscopic objects would seem to be the micrometer screw, which is applied with so much success, and with results of such extreme precision, in astronomical instruments. Various methods of applying it to the microscope will suggest themselves to every one who is familiar with its uses in the observatory. Let two filaments of spider's web, or micrometric wire, be extended at right angles across the field in the focus of the eye-piece. These will divide the field horizontally and vertically at right angles, intersecting at its centre, as shown in fig. 25. Now suppose the stage supporting the object is capable of being moved by a micrometer screw, having for example one hundred threads to the inch. Let the object be placed first so that its length shall be horizontal, and let the slip be adjusted so that the vertical micrometric wire *b b′* shall coincide with one of its extremities. Let the micrometer screw be now turned so that the object shall move horizon-

Fig. 25.



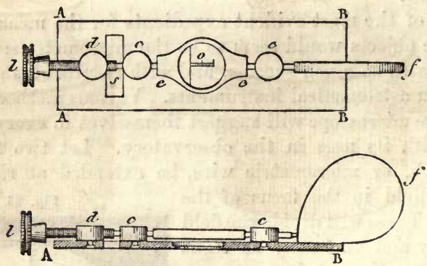
tally. It will appear to pass gradually under the vertical wire until its other extremity shall coincide with that wire. If then the number of complete turns, and parts of a turn of the screw be counted, the length of the object then will be known. Thus, if at the end of every complete turn, the screw produce an audible sound like the tick of a clock, the observer can count the complete turns, and if the circumference of the head be divided into 100 parts, and that an index be fixed upon the stage to indicate the position of the head at the commencement, the decimal parts of a turn can be ascertained, each division of the head corresponding to the 100th part of a complete turn, and therefore to the 10000th of an inch.

By turning the stage so that the screw will cause the object to move across the field in the direction of the vertical wire, its dimensions in the other direction can be ascertained.

59. A simple and ingenious micrometer for ascertaining the dimensions of such objects as would bear a slight pressure without change of form, was invented by M. Le Baillif. A plan and vertical section or side view of this are shown in fig. 26.

Two upright pieces, *c c*, are fixed in a slip of copper, formed like one of the slides, having a circular hole in its centre, in

Fig. 26.



which is set a plate of glass, on which a scale *o* is engraved. Upon this is placed a moveable piece, *e e*, having a similar hole and plate of glass, with a fine line engraved upon it at right angles to the scale, so that when it is moved from left to right this fine line will coincide necessarily with all the divisions of the scale. From this piece, two rods proceed, which pass through holes in the upright pieces *c c*, and one of them is reacted upon by a piece of watch-spring, *f*, while the other abuts against the end of a fine screw, *l*, which moves in a nut, *d*.

When an object is to be measured, the index line upon the upper glass disc is brought to coincide with the first division or

zero of the scale by turning the head *l* so as to cause the screw to retire from the piece *e e*, the spring *f* then pressing this piece towards the screw. The object to be measured is then inserted between the end of the rod projecting from *e* and the screw, and consequently the piece *e e* and the index line engraved upon it will be pushed from left to right through a space equal to the thickness of the object. This thickness may then be ascertained by observing with the microscope the division of the scale to which the indicating line has been advanced.

60. A micrometer, having some resemblance to this, but made more applicable to the general purposes of microscopic measurement, has lately been contrived by Mr. Jackson, a description of which is published in the "Transactions of the Microscopical Society."

A disc of glass, upon which a micrometric scale is engraved, is set in a thin plate of brass, which moves with a sliding motion on another plate, in which a corresponding hole is made. The former is like that of M. Le Baillif, urged by a fine screw in one direction, and driven back by a spring in the other, as shown in fig. 24.

Fig. 27.

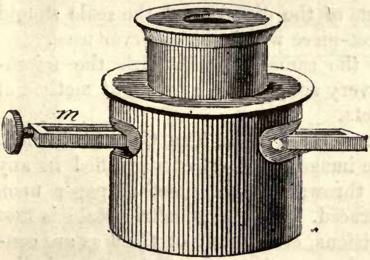
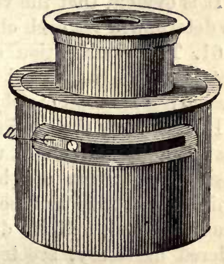


Fig. 28.



This micrometer slide is inserted in the tube of the eye-piece by openings in the sides of the tube, as shown at *m* in fig. 27, which openings can be closed when the micrometer is not used by sliding covers, as shown at *a*, fig. 28.

It is easy to see how this contrivance is applied. The scales magnified by the eye-glass are projected upon the optical image of the object produced by the object-glass, and this image may be made to move so as to bring its extremity to coincide with the first division of the scales. The scale will then show not only the dimensions of the entire object, but those of its parts. The object may be turned in any direction relatively to the scale that may be desired, by means either of the hand or the stage adjustments.

It is necessary, however, before applying this micrometer to the measurement of objects, to ascertain the value of the divisions of the scale relatively to the object, since the immediate subject of its measurement is, not the object itself, but the optical image of the object produced in the focus of the eye-piece by the object-glass; and this preliminary valuation is the more necessary, inasmuch as the relative magnitude of the image, compared with that of the object, will vary with the power of the object-piece.

To ascertain, then, the value of the divisions of the scale, let another micrometric scale, the divisions of which are known, be placed upon the stage. An image of this scale, magnified as that of an object would be, will then be formed in the focus of the eye-piece, and the other scale will be seen projected upon it. Let the position of the two scales be so adjusted by the stage arrangements that the first division of the one shall be projected on the first division of the other. By observing then the next divisions of the two which coincide, the relative value of the scales will be known. Thus if ten divisions of the eye-piece scale exactly cover 100 divisions of the other, and if each division of the latter be the 1000th of an inch, one division of the eye-piece scale will correspond to the 10000th part of an inch in the dimensions of an object.

It is evident that the value of the divisions of the scale should be determined for each object-piece which the observer uses.

61. The combination of the camera lucida with the micrometric scale has supplied a very simple and convenient method of measuring microscopic objects.

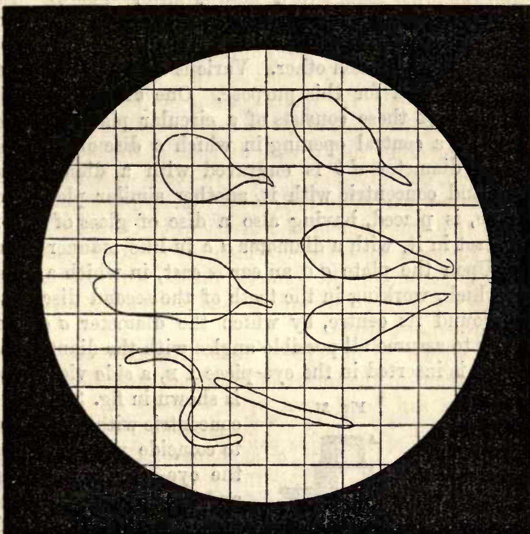
It has been shown in our Tract upon The Camera Lucida, that by that instrument the image of an object magnified in any desired proportion can be thrown upon a sheet of paper upon which its outline can be traced. The micrometric scale is first thus projected, and its divisions, or as many of them as are considered necessary, are traced upon the paper. Another similar series of divisions being traced at right angles to the former, the part of the paper corresponding to the field of view is divided into a system of squares, like those into which a map is divided by the lines of latitude and longitude. The micrometric slide being removed from the stage, the slide with the object is substituted for it, and the observer sees the image of the object similarly magnified projected upon the paper, already spaced out by the squares. He can therefore count the number of squares occupied by its length and breadth, and by the length and breadth of its several parts, or, better still, he can trace its outline upon the paper, so that its dimensions and those of all its parts can be exactly ascertained. Thus, if each division of the scale is the 1000th of an inch, the side of each square will represent the

1000th of an inch, and these sides may themselves be easily subdivided into ten or 100 parts, so as to carry the measurement to 10000ths or 100000ths of an inch.

In fig. 29 the field of view is represented spaced out in this manner, with the outlines of objects traced upon it.

Such a scale once drawn upon the paper, will serve for the measurement of any objects which may be submitted to the microscope; but it is most essential that in all such measurements the paper be kept at exactly the same distance from the camera, and that neither the object-glass, the eye-glass, nor the stage shall suffer any change in their relative positions.

Fig. 29.



It has been shown that the magnitude of the image received on the paper increases with the distance of the paper from the camera. If, therefore, the paper be placed at a greater or less distance from the camera to receive the image of the object than that at which it was placed to receive the image of the micrometric scale, the image of the object will be produced upon a scale greater or less than that on which the image of the micrometric scale was produced, and consequently the one cannot be taken as a measure of the other.

If any change be made in the relative positions of the eye-

piece, object-piece, and stage, a corresponding change would be made in the magnifying power of the instrument, and a consequent change in the dimensions of the picture of any object projected by the camera on the paper, though no change be made in the distance of the paper from the camera.

In fine, the method of measuring the actual dimensions of a microscopic object by means of a scale drawn with the aid of the camera, requires that the instrument and the paper shall be in precisely the same state when the image of the object is projected on the paper as they were when the scale was drawn upon the paper.

If this condition be observed, measurements can be made by the camera with all the necessary facility and precision.

62. In microscopic researches it is frequently necessary to measure the angles at which the lines which form the contour of objects are inclined to each other. Various forms of *goniometers* * have been contrived for this purpose. One of the most simple and convenient of these consists of a circular plate of brass C C, fig. 30, having a central opening in which a disc of glass is set, on which a diameter *d b* is engraved with a diamond point. Upon this, and concentric with it, another similar plate, toothed at the edge, is placed, having also a disc of glass of the same magnitude set in it, with a diameter *a c* in like manner engraved upon it. Upon the plate C C an ear is cast, in which a pinion is inserted, which, working in the teeth of the second disc, gives it a motion round its centre, by which the diameter *a c* is made successively to assume all possible angles with the diameter *d b*.

This piece is inserted in the eye-piece A B, a side view of which is shown in fig. 31, so as to be concentric with the lenses, and to coincide with the focus of the eye-lens. The lines *a c* and *b d* will then be seen projected on the image of the object, and if the vertex of the angle it is desired to measure

Fig. 30.

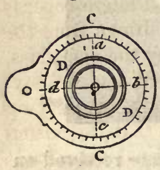
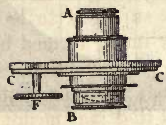


Fig. 31.



be brought, by means of the stage adjustments, to coincide with the centre O of the disc *a b c d*, where the two engraved diameters intersect, and so that one side of the angle to be measured shall coincide with the fixed line *d b*, the line *a c* can be turned by the pinion F, until it shall coincide with the other side. A graduated circle which surrounds the disc will then show the magnitude of the angle at which *b d* and *a c* are inclined.

* From the Greek word γόνυ (*gonu*), knee.

THE MAGNIFYING POWER.

63. It has been well said, that a question clearly put is half resolved. There is no term in microscopic nomenclature so familiar to the ear, and so flippant on the tongue, as the "magnifying power;" yet there is none respecting which there prevail so much confusion and obscurity. The chief cause of this is the neglect of a clear and distinct definition of the term.

It has been already shown, that the magnitudes observed with the microscope are visual, not real. We can say that such or such an object seen in the microscope has a magnitude of so many degrees, but not at all one of so many inches. Strictly speaking, the same is true of all objects seen in the ordinary way; but in that case the mind is habituated to form an estimate of their real magnitudes, by combining the consideration of their apparent magnitudes with their distances. It is true that we are unconscious of the mental operation from which such estimates result, but it is not the less real. Our unconsciousness of it arises from the force of habit, and the great quickness of the acts of the mind. Every one who has been familiar with intellectual phenomena knows that such unconsciousness is found to attend all such acts as are thus habitual and rapid.

64. But when objects are looked at in a microscope, the mind not only does not possess the necessary data to form such an estimate, but the conditions under which the visual perceptions are formed are so unusual, and, so to speak, unnatural, that it is incapacitated to form an approximate estimate even of the visual, to say nothing of the real, magnitude of the object of its perception.

The visual magnitude of an object, as seen in a microscope, is the angle of divergence of lines supposed to be drawn from the eye to the limits of the imaginary image formed by the eye-glass, which is the immediate object of perception. When we say, therefore, that the instrument has such or such a magnifying power, every one will comprehend that it is meant that this visual magnitude is so many times greater than the visual magnitude which the object would have, if it were seen in the usual way without the interposition of any optical expedient.

So far all is clear, and so far there can be no difference of opinion on the point, provided only that the latter member of the sentence be clearly defined. What is the "visual magnitude *seen in the usual way?*" There are many ways of looking at an object, and "the usual way" depends much on the magnitude of the object. We can see well enough the dome of St. Paul's Cathedral at the distance of half a mile, while we cannot see a

small insect at the distance of a yard. The same object may be viewed at different distances, and will have different visual magnitudes, these magnitudes being greater as the distance is less. The visual diameter of a small object, seen from the distance of a yard, is three times less than when seen from the distance of a foot. It appears, therefore, that the "visual magnitude of an object seen in the usual way with the naked eye," is a term of comparison which, without some further condition to limit it, has no fixed meaning, and consequently leaves the "magnifying power" of which it is made the standard, altogether vague and indefinite.

65. The visual magnitude therefore which is made the standard of magnifying power, must be the visual magnitude at some arbitrary distance conventionally assumed. As we have already stated, it has been generally agreed, since micrography has taken the rank of a special branch of science, to adopt ten inches as the standard distance. This distance is recommended not merely on account of the arithmetical facility which arises out of its decimal character, but because it agrees sufficiently for all practical purposes with the standard derived from the measures of other countries. In France, for example, the standard usually adopted is twenty-five centimètres, which is equal to 9·427 inches, being less than ten inches by only about the sixth of an inch.

According to this convention, then, the magnifying power of a microscope would be the number of times the visual diameter of the object viewed with the microscope is greater than its visual diameter viewed by an eye placed at ten inches from it. Thus, if the visual diameter of an object seen at the distance of ten inches be fifteen minutes of a degree, and the visual magnitude of the same object seen with a microscope be two and a half degrees, or 150 minutes, the magnifying power will be ten.

But an objection will even still be raised. The object may be so small that at the distance of ten inches it would not be visible at all with the naked eye. Nay, it may be, and in the case of microscopic objects often is, so minute that it would not be perceptible to the naked eye at any distance, however small. In that case it may be asked, What is to be understood by "its visual magnitude at the distance of 10 inches?"

This point will require some explanation. There is a certain limit of magnitude within which an object will cease to make any sensible impression of its magnitude or form upon the eye. This minor limit of magnitude varies with different individuals, and, in the case of the same individual, with different objects according to their colour, illumination, the ground on which they are projected, and many other conditions which it is not here necessary to

discuss. It will suffice to say that there is such a limit. If the visual angle formed by lines diverging from the eye to the extremities of the object be within this limit, the object will not be perceived; or, to speak with more rigour, its magnitude and form will not be perceived.*

In such cases, therefore, the visual magnitude of an object, without the intervention of the microscope, must be understood to mean the angular divergence of the rays which would be drawn from a point placed at ten inches from the object to its extremities. This would be the visual magnitude of the object "*if it could be seen*" at that distance.

In fine, therefore, the definition of the magnifying power of a microscope will be clear, distinct, and adequate, if it be stated thus:—It is the quotient which would be obtained by dividing the visual magnitude of the object, as seen in the microscope, by the visual magnitude which the object would have to a naked eye placed at ten inches distance from it, supposing the eye to have sufficient sensibility to perceive it at that distance.

Every one is more or less familiar with real magnitude, so that when an object of ordinary dimensions is placed before them they can give at least a rough estimate of its actual dimensions. The same facility of estimating visual magnitude does not exist, although, in fact, we receive the impressions of visual much more frequently than those of real magnitude. The estimate of visual magnitude, however, enters into all microscopic inquiries as an element and condition of such importance, that all those who use the instrument, whether for the purposes of serious research or rational amusement and instruction, would do well to familiarise themselves with it. Some observations illustrative of such sensible impressions will therefore, we presume, be not unacceptable to our readers.

66. Our great familiarity with real magnitude arises from our intimate knowledge of certain standard units by which it is counted. There is no one, however little educated, that has not a pretty clear notion of the length expressed by an inch, a foot, and a yard. Let us see whether we may not enable any one with common attention to acquire an equally clear notion of the standard units of visual magnitude.

Every one is familiar with the apparent magnitude of the disc of the full moon. It is visible to the whole world, and seen for several nights in each month during the entire life of every individual. Now it happens that the visual magnitude of its diameter

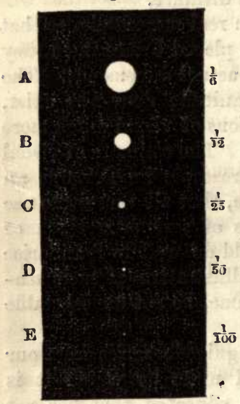
* The fixed stars are visible as mere luminous points, but their forms and magnitudes are not perceivable, owing to the extreme smallness of their visual angle produced by their enormous distances.

is just *half a degree*, which means, that the angular divergence of lines drawn from the eye to the extremities of the diameter is the same as that of two lines drawn from the centre of a circle to the extremities of an arc, which is the 720th part of the entire circle. Every one, therefore, who is familiar with the appearance of the full moon, will be as familiar with the meaning of a visual angle of half a degree, and, consequently, of a degree as they are with the real magnitude of an inch or a foot.

The distance of the moon has been ascertained to be 120 times its own diameter, and it is evident that any circular disc whatever, whose distance from the eye is 120 times its own diameter, will have a visual angle equal to the diameter of the moon, and therefore to half a degree; and, consequently, one whose distance is sixty * times its own diameter, would have a visual angle of a degree.

Thus, in fig. 32, there are five white discs shown upon a black ground: the diameter of the first is the 6th of an inch; that of the second, the 12th; that of the third, the 25th; the fourth, the 50th; and the fifth, the 100th. If these be held at ten inches from the eye, the first disc, A, will have a visual angle of 1°; the second, B, one of 30′; the third, C, about 15′; the fourth, D, $7\frac{1}{2}'$; and, in fine, the fifth, E, $3\frac{3}{4}'$.

Fig. 32.



It follows, therefore, that an object which when viewed with a magnifying power of 1000, appears with the same visual diameter as the moon, or as the disc B, fig. 32, placed at 10 inches from the eye, must have a real diameter no greater than the 12000th part of an inch.

Having familiarised himself with some such standards of visual magnitude as these, and once knowing the magnifying power of his instrument, an observer can easily make a rough estimate of the real magnitudes of the objects under view.

67. But for this, as well as many other purposes of microscopic research, it is necessary that the actual magnifying power of the instrument be ascertained.

The most simple and direct means of accomplishing this are supplied by the camera lucida.

* More strictly 57·3 times; but the round number will be sufficient for the above illustration.

Let a micrometric scale, such as we have already described, be placed on the stage, the instrument focussed, the camera attached, and a sheet of paper placed at 10 inches from it. An image of the scale being seen on the paper, let any two contiguous divisions of it be marked with the pencil. Let the distance between these marks be then exactly measured, and let it be divided by the actual length of the divisions of the scale. The quotient will be the magnifying power.

Thus, for example, let us suppose that the micrometric scale is the 25th part of an inch, and that this length is divided into 100 parts, each of these parts will be the 2500th part of an inch. Now suppose that it is found that the distance between the images of two contiguous divisions on the paper, is four-tenths of an inch. It will follow that the visual magnitude of a division of the scale is magnified in the proportion of $\frac{1}{2500}$ to $\frac{4}{10}$, that is, as 1 to 1000. The magnifying power would therefore be a thousand.

There are other methods of ascertaining the magnifying power, but this is so simple, so easily produced, and so precise, that we shall not detain the reader by any notice of others.

Microscopes being generally supplied with several object-glasses, and eye-pieces, the observer and amateur would do well once for all to ascertain the magnifying powers of all the possible combinations of them, and to tabulate it and keep it for reference.

68. It is often asked, What are the dimensions of the most minute object which a microscope, having a given magnifying power, is capable of rendering distinctly visible?

The answer to this question will depend on the answer to another; What are the least dimensions of the same object, with which it would be distinctly visible, at ten inches distance, with the naked eye?

Whatever be the latter dimensions, the former will be just so many times less as there are units in the number which expresses the magnifying power.

Thus, for example, if the smallest linear dimensions with which the object could be distinctly seen without a glass at 10 inches distance were the 300th part of an inch, a microscope having a magnifying power of 500 would render such an object equally visible if its linear dimensions were only the $300 \times 500 = 150000$th part of an inch.

It is generally considered that the smallest disc of which the form can be distinguished by the naked eye, being properly contrasted with the ground upon which it is seen, is one which would have a visual angle of one minute; and since a line measuring the 360th part of an inch, placed at ten inches distance, would

have that visual angle, it would follow that the smallest object of which the form could be rendered distinctly visible by a microscope of a given magnifying power, would be one whose linear dimensions are as many times less than the 360th part of an inch as there are units in the number expressing the magnifying power.

It must not be forgotten, however, in considering such points, that the smallest object whose form can be distinctly seen at a given distance without a glass, depends on many conditions, some connected with the object, and some with the observer, as has been already stated.

Many persons fall into the error of supposing that the excellence of a microscope is to be determined by the greatness of its magnifying power. On the contrary, that instrument must be considered the most efficient which renders the details of an object perceptible with the lowest power. Distinctness of definition, by which is meant, the power of rendering all the minute lineaments clearly seen, is a quality of greater importance than mere magnifying power. Indeed, without this quality, mere magnifying power ceases to have any value, since the object would appear merely as a huge misty silhouette.

Sufficiency of illumination is another condition which it is difficult to combine with great magnifying power, but which is absolutely necessary for distinct vision.

If two instruments show the same object with equal distinctness of definition and with sufficiency of illumination, one having a higher magnifying power than the other, then it must be admitted that the one which bears, with such conditions, the higher power is the more efficient instrument.

The mere magnifying power depends on the focal length of the lenses, the illumination on the angle of aperture, and the distinctness of definition on the extent to which those conditions have been fulfilled which confer upon the combination of lenses composing the instrument, the qualities of aplanatism and achromatism.

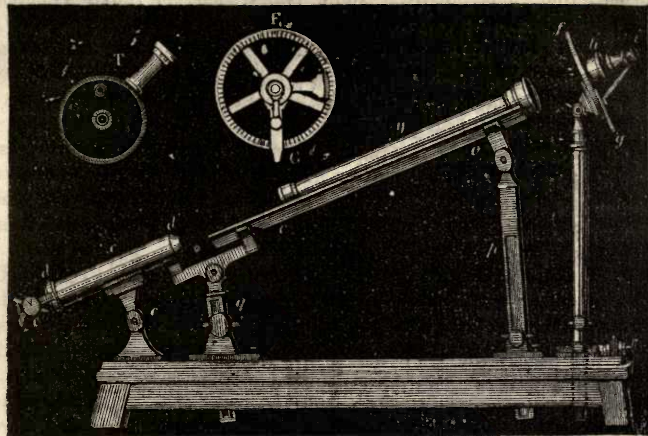


Fig. 35.—BIOT'S POLARISCOPE.

THE MICROSCOPE.

CHAPTER V.

MICROPOLARISCOPE: 69. Polarisation.—70. Condition of a polarised ray.—71. Polarisation by double refracting crystals.—72. Their effect upon rays of light.—73. The micropolariscope. THE MOUNTING OF MICROSCOPES: 74. Conditions of efficient mounting.—75. Frauenhoffer's mounting.—76. Methods of varying the direction of the body. CHEVALIER'S UNIVERSAL MICROSCOPE: 77. Mounting of this instrument.—78. Method of rendering it vertical.—79. Method of adapting it to the view of chemical phenomena.—80. Method of condensing the light upon the object. ROSS'S IMPROVED MICROSCOPE: 81. Useful labours of Mr. Ross.—82. Details of his improved microscope.

THE MICRO-POLARISCOPE.

69. WHEN a ray of light has been reflected from the surface of a body under certain special conditions, or transmitted through certain transparent crystals, it undergoes a remarkable change in its properties, so that it will no longer be subject to the same effects of reflection and refraction as before. The effect thus produced upon it, has been called POLARISATION, and the ray or rays of light thus affected are said to be POLARISED.

The name POLES is given in physics in general to the sides or ends of any body which enjoy or have acquired any contrary properties. Thus, the opposite ends or sides of a magnet, have contrary properties, inasmuch as each attracts what the other repels. The opposite ends of an electric or galvanic arrangement are, for like reasons, denominated poles.

70. Following the common rule of analogy in nomenclature, a ray of light which has been submitted to reflection or transmission under the special conditions referred to, has been called polarised light; inasmuch as it is found that the sides of the ray which lie at right angles to each other, possess contrary physical properties, while those of a ray of common or unpolarised light possess the same physical properties.

To illustrate the relative physical condition of common light and polarised light, we may compare a ray of common light to a round rod or wire of uniform polish and uniformly white, while a ray of polarised light may be compared to a similar wire, two of whose opposite sides are rough and black, while the other opposite sides at right angles to these are polished and white. Thus, if A B C D, fig. 33, be a section of the former, the entire circumference A B C D is white and polished, and if A′ B′ C′ D′

Fig. 33.

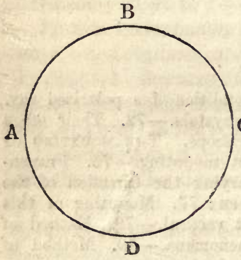
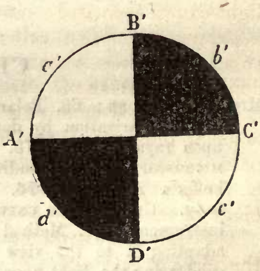


Fig. 34.



be a section of the latter, A′ B′ and C′ D′ will be white and polished, while B′ C′ and D′ A′ will be black and rough.

A group of physical properties, very numerous and complicated, characterise the polarised state of light, the discussion and exposition of which, constitute the subject of an extensive and important section of optics. It would be obviously impossible here to convey to the reader any general idea of these; nevertheless, as an illustration of them, one of the most frequent occurrence may be mentioned. If a ray of common light fall upon a smooth and polished surface, it is always reflected according to the well-known laws of reflection, no matter what side of it may be pre-

sented to the reflecting surface. If a polarised ray, however, fall at a certain inclination upon the same surface, it will be reflected or absorbed according to the side of it which is turned towards the reflecting surface. Thus, if the side A′ B′ or C′ D′ be presented towards the reflecting surface, the ray will be reflected as if it were common light, but if the side B′ C′ or A′ D′ be turned towards the reflecting surface, it will not be reflected at all, but will be, as it were, smothered or extinguished.

The sides A′ B′ and C′ D′, which are opposite to each other, have, therefore, a property contrary to that of the sides B′ C′ and A′ D′, so that they are respectively called the poles of the ray, just as the ends of a voltaic circuit having contrary electric properties are called the positive and negative poles of the voltaic battery, and the ends of a magnet are called its boreal and austral, or south and north poles.

The effects which polarised light produces when it falls upon, or is transmitted through, various substances, more especially such as are in the state of crystallisation, are of the highest physical importance, being in most cases the indication of molecular and other properties, by which optics has been placed in relation with, and has become the handmaid of, almost every other branch of physical science.

71. There are various expedients by which a ray of common light can be polarised. It will be polarised if it be reflected at a certain inclination, called from that circumstance the angle of polarisation, from certain surfaces. Each substance has its own angle of polarisation. That of glass, for example, is $35\frac{1}{4}°$. It is also polarised if it pass through certain transparent crystals. Some of these, while they polarise the ray, split it into two, both being polarised, but in planes at right angles to each other; that is, for example, the sides A′ B′ and C′ D′ being white in one, and black in the other.

The well-known mineral called Iceland spar is an example of this class of crystals.

Such crystals are called double-refracting crystals, because the two rays into which the ray of common light is split are refracted by the crystal in different directions, and according to different laws.

When a polarised ray is transmitted through such a crystal, according to certain conditions, it will either pass through it, as it would through any ordinary transparent medium, or will be extinguished by it, according to the side of the ray to which certain faces of the crystal are presented. Such crystal is related to the poles of the ray, therefore, in the same manner as the reflecting surface already described.

72. If either the reflecting surface or the crystal, placed under the necessary conditions, be carried round a polarised ray, A′ B′ C′ D′, so as to be successively presented to all sides of it, the ray will be completely reflected or transmitted when it is presented to *a′*, the middle of the side A′ B′. As it is moved from *a′* towards *b′*, the quantity of light reflected or transmitted will be less and less, until it comes to *b′*, when none will be reflected or transmitted, the ray being wholly extinguished. As it is moved from *b′* to *c′*, the light reflected or transmitted, small in quantity at first, will be continually greater and greater until it comes to *c′* the middle of C′ D′, when the ray will be wholly reflected or transmitted. As it is moved from *c′* towards *d′*, the quantity of light reflected or transmitted is less and less, until arriving at *d′* the ray is altogether extinguished. After passing from *d′* towards *a′*, the light reflected, at first small, is more and more in quantity until it comes in fine to *a′*, when the ray is, as at first, wholly reflected or transmitted.

73. An instrument adapted to show the effects of polarised light upon bodies on which it is incident or through which it is transmitted, is called a POLARISCOPE, fig. 35, p. 65, and a polarising microscope or MICRO-POLARISCOPE, is a microscope by which the observer is enabled to project polarised light upon the objects, and to observe its effects when transmitted or reflected by them.

Micro-polariscopes have been constructed in various forms, some depending on polarisation by reflection, and some on polarisation by transmission.

One of the most simple and most generally useful, consists of two prisms of Iceland-spar, one of which, P, is placed under the stage, so that the light by which the object is illuminated must previously pass through it, and the other P′ is placed in the body of the instrument between the object-glass and the eye-glass, so that before producing the image, the rays must pass through it.

The light proceeding from P, and projected upon the object, being polarised, and received, after passing through the object-glass, by P′, will be wholly or partially transmitted, or altogether extinguished, according to the sides or poles of the ray to which certain faces of the prism are presented. If, therefore, the instrument be so mounted that the prism P′ can be turned round its axis, its faces can be presented successively to all sides of the rays, so that the light will be in a certain position wholly transmitted, and the image will be seen strongly illuminated. When the prism is gradually turned round, the light transmitted will be less and less, until the prism has been turned through a quarter of a revolution, when the light will be wholly extinguished, and the image will disappear. Continuing to turn

the prism, the image will gradually re-appear, at first faintly, and by degrees brighter, until the prism is moved through another quarter of a revolution, when the image will be again seen fully illuminated. Like changes will take place during the other two quarters of a revolution.

Similar effects will be produced if the prism P′ be fixed, and P be turned round its axis. In this case, by moving the polarising prism P round its axis, the polarised ray is made to revolve, because the position of its poles a' b' c' d' has always a fixed relation to the faces of the prism P. Since, therefore, the polarised ray revolves, it presents successively all its sides to the prism P′, by which it is accordingly alternately transmitted, and absorbed wholly or partially in the same manner, exactly as if the ray were fixed, and the prism P′ carried round it.

By the appearance and disappearance of the image corresponding with the position of the prism P′, the position or direction of the planes of polarisation A′ C′ and B′ D′ of the polarised ray is known.

These effects will be produced if the objects through which the light is transmitted or by which it is reflected have themselves no polarising influence. But if they have, various other phenomena will ensue, depending on the character and degree of that influence; but whatever it be, the state of the light, which proceeding from the object-glass forms the image, will be ascertained by the prism P′, which is consequently called the *analysing prism*, the other P being denominated the polarising prism.

Various physical characters are thus discovered in the objects submitted to the microscope by determining the optical effects they produce on polarised light, and many striking and beautiful phenomena are developed.

THE MOUNTING OF MICROSCOPES.

74. The methods of mounting microscopes, so as to adapt them to the convenience and the ease of observers, are very various, depending on the purposes to which they are applied, their price, the exigencies of the purchaser, and the skill, taste, and address of the maker.

The qualities which it is desirable to confer upon the stand and mounting of the instrument are simplicity of construction, easy portability, smoothness and precision in the action of all the moving parts, and such combinations as may cause any tremor imparted to the stand to be distributed equally over every part of the mounting. These capital objects are attained very completely in all the mountings of the best makers, British and Foreign.

The most simple, and consequently the cheapest description of mounting, is that in which fewest parts are moveable. The only parts of a compound microscope which are *necessarily* moveable are those by which the instrument is focussed, and the object illuminated. The most simple mechanical expedient for effecting the former is a rack and pinion attached either to the body or the stage, and for the latter the suspension of the reflector upon an horizontal axis, so that it can be inclined at any desired angle to the axis of the body and the stage.

Whatever be the form or disposition of the stand, it is essential that the axis of the object-piece should pass through the centre of the stage, and that the reflector should be so set as to be capable of reflecting light in the direction of this axis. The body is generally a straight tube, the axis of the eye-piece and object-piece being in the same straight line. In the case of instruments mounted after the model of Professor Amici, however, the body consists of a tube having two parts with their axes at right angles, the axis of the object-piece being vertical, while that of the eye-piece is horizontal. In this case, a prism is fixed in the angle of the tube, at an angle of 45° with the axes by which the rays proceeding vertically from the object-piece are reflected horizontally to the eye-piece, on the principle already explained (30).

75. One of the most simple models for the mounting of a compound microscope was contrived by Frauenhoffer so early as 1816, long before achromatic lenses were produced. This model, owing to its great simplicity, convenience, and cheapness, is still extensively used for the lower priced instruments, especially by the continental makers.

The body of the instrument is attached to a vertical pillar, fig. 36, p. 49, and its axis is permanently vertical. It is focussed by a rack and pinion, worked by a milled head on the right of the observer. The stage is fixed in its position, and placed on the top of a short tube, in the lower part of which the reflector is suspended on an horizontal axis, so that it can be placed at any desired obliquity to the axis of the instrument, and thus can always throw a beam of light upwards to the object. One side of this mirror is concave, and the other plane.

For the illumination of opaque objects, a lens is attached by a jointed arm to the upper part of the pillar, on which the instrument is supported.

M. Lerebours, of Paris, makes excellent microscopes on this model, with a triple achromatic object-piece and other accessories, which he sells at the very moderate price of 90 francs (3*l.* 12*s.*). Several thousands of these have been sold.

76. The attitude of an observer stooping the head to view an object in a microscope, whose eye-piece is vertical, is found to be attended with much inconvenience, especially if the observation be long continued. This has constituted the ground of a very general objection to vertical microscopes. Nevertheless there are many cases in which it would be inconvenient to place the stage in an inclined or vertical position, as, for example, when observations are made on liquids. In all such cases the model of Amici's stand presents obvious advantages, the observer looking horizontally, while the axis of the object-piece is vertical, and consequently the stage horizontal.

Most of the better class of instruments, however, are so mounted that any direction whatever can be given to the axis of the body. Various mechanical expedients are used for accomplishing this, most of which are analogous to the methods of mounting telescopes. In some, the instrument with its appendages is supported upon two uprights of equal height by means of trunnions, which pass through its centre of gravity, so that it turns upon its supports like a transit instrument, the axis of the body being capable of assuming any inclination to the vertical. The observer, therefore, may at pleasure look obliquely or vertically downwards, or obliquely upwards, as may suit his purpose.

Similar motions are also produced by mounting the instrument upon a single pillar by means either of a cradle-joint, such as is generally used for telescope-stands, or a ball and socket. Stands of this form are attended with the advantages of offering greater facility for moving the instrument horizontally round its axis.

In the attainment of all these objects, as well as in the production of eye-pieces and object-pieces of capital excellence, the leading makers of London, Paris, Berlin, and Vienna, have honourably rivalled each other, and it may be most truly said, to their credit, that if some have excelled others in particular parts of the instrument, there is not one who has not in some way or other contributed by invention or contrivance to the perfection either of the optical or mechanical parts.

Much however is also due to the eminent philosophers and professors who have more especially devoted their attention to those parts of science in which the microscope is a necessary means of observation, and foremost among these is the patriarch of optical science, Sir David Brewster. It would be difficult to name the part of the instrument, or of its accessories or appendages, for the improvement of which we are not deeply indebted to this eminent man. Among the more recent philosophers who have contributed to the advancement of micrography, and by whose researches and suggestions the makers have been guided,

may be mentioned Messrs. Goring, Lister, Coddington, Quecket, Mandl, Dujardin, Le Baillif, Seguier, De la Rue, and numerous others.

The eminent makers of the British and Continental capitals are well known. Good instruments of the low-priced sort are made by nearly all the opticians; but those who have more especially devoted their labours to the microscope, are Messrs. Ross, Smith and Beck, Powell and Lealand, Pritchard, Varley, and Pillisdier, in London; Messrs. Nachet, Charles Chevalier and George Oberhauser, of Paris; MM. Ploessel and Schieck, of Vienna; and M. Pistor, of Berlin.

Without the intention of assigning any relative precedence to these artists, we shall now present a brief description of some of the instruments, according as they are severally mounted by them.

CHEVALIER'S UNIVERSAL MICROSCOPE.

77. The mounting of this instrument has always appeared to me to offer as many conveniences and advantages to the observer as can be combined in such an apparatus.

A mahogany case A, fig. 37, p. 1, containing a drawer B, in which the instrument and its appendages are packed when out of use, serves as its support. A strong brass pillar, C C, is firmly screwed into the top of the case, and upon this pillar the entire instrument is supported.

The pillar C C sometimes is made in two lengths, which are screwed one upon the other, by which means the height of the instrument may be varied at pleasure, either one or both lengths being used.

An arm E *c* is attached by a joint at E to the summit of the pillar C C, so that it can be moved on the joint E with a hinge motion, and may thus be placed at any angle with the pillar C C. In the figure it is represented at right angles with C C.

To the middle D of the arm E *c*, a square brass bar D F G is attached at right angles to E *c*, so that when E *c* is at right angles to C C, the bar D F G is parallel to C C. In the face of the bar D F G, which is presented to C C, a rack is cut.

Two square pieces P and M are fitted to the bar D F G, and are moved at pleasure upwards and downwards upon it by means of pinions, having milled heads O and N.

To the square piece P is attached the stage Z, upon which the object is placed, and maintained in its position by two springs, one of which is shown in the figure. This stage is provided with several adjustments, which have been already explained (31 *et seq.*). It will be sufficient for the present to observe that it is capable of being moved upwards and downwards with the

square piece P, to which it is attached by turning the milled head O, and that a slower motion, to give more exact adjustment, is imparted to it by a fine screw having a milled head at Q.

To the square piece M is attached the illuminator H, on one side, K, of which is a concave reflector, and on the other, I, a smaller plane reflector. This illuminator has two motions, a horizontal or lateral one upon a joint at M, by which it can be placed at pleasure either vertically under the centre of the stage Z, or at a limited distance on one side or other of the vertical through the centre of the stage. The circular illuminator is suspended at two points diametrically opposite in a semicircular piece, and may be placed at any desired inclination to the vertical, and with either reflector upwards by means of the milled head I.

From the lowest part of the pillar C C a piece projects, having a cavity corresponding with the size and form of the bar D F G, into which that bar enters when it is vertical as represented in the figure, and in which it is held by the pin at G.

The body of the microscope, as shown in the figure, is rectangular. The eye-tube T is moved backwards and forwards in the body R by a pinion U working in a rack. The eye-piece S is inserted in this tube, and the eye is protected from the light by a circular blackened screen, seen edgeways in the figure. The rectangular tube V X is inserted by a bayonet-joint in the remote end of the body R, in which it is capable of being turned, so that the object-tube X shall be horizontal, to enable the observer with greater facility to screw on or to change the object-glasses at Y.

The body is attached to the bar E *c* by a joint at *c*, upon which it can be turned, by which means other positions can be given to the instrument, as will presently be explained.

An assortment of object-glasses is supplied, which may be screwed at pleasure upon Y. They are adapted to each other in sets of three, so that one, two, or three may be attached to Y according to the power required.

In the angle *b* of the body, a rectangular prism is fixed, by which the rays proceeding upwards from Y are reflected horizontally along the axis of R to the eye-piece, on the principle explained in 30.

Several eye-pieces of different powers are supplied with the instrument.

The magnifying power may be varied within certain narrow limits by moving the eye-tube in or out by the pinion U, and at the same time adjusting the focus by the pinions O and Q, which move the stage Z. When it is desired to augment the power, the

tube T is drawn out so as to lengthen the body, and the stage Z is brought nearer to the object-glass Y. The effect of this is to increase the dimensions of the optical image produced in the eye-piece by the object and field glasses, as explained in 6.

If a greater increase of magnifying power be desired, the eye-piece may be withdrawn, and a shorter one substituted for it.

But these expedients are only useful when the increase of power required is confined within comparatively narrow limits. All greater amplification must be produced by the object-glasses. These, as has been explained, are made in sets of three, having different powers. The lowest power will be obtained by screwing the first lens only of the lowest set upon Y; the next by screwing on the second; and the next by screwing on the third; by which the powers of all the three will be combined.

If it be desired to obtain a still higher power, these lenses being taken off, the first lens of the set next in order is screwed on, then the second, and in fine the third, by which another series of three increasing powers is obtained.

In this manner, by a suitable assortment of object-glasses and eye-pieces, any desired degree of amplification can be obtained.

The height of the case A and the length of the pillar C C are so arranged, that when the case is placed upon a table of the usual height, the eye of an observer of average height when seated will be on a level with the eye-piece S.

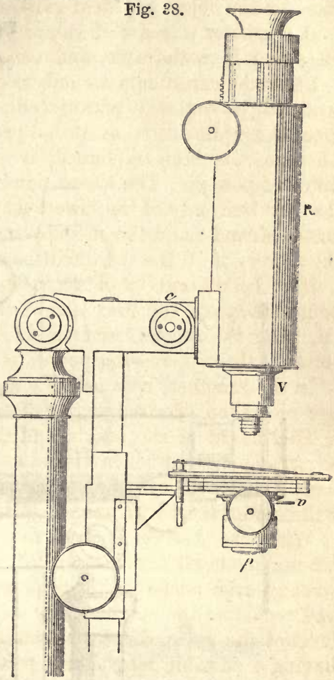
When the observer is about to submit an object to examination, having mounted the instrument, placed it firmly upon a table with an even surface so as to prevent any rocking or instability, and regulated the height of his seat so that his eye shall be at the level of the eye-piece, he selects an eye-piece and object-glasses having a suitable magnifying power, and in doing this it is most important to commence with a low power, to be gradually increased. For this purpose, one object-glass of a set is first screwed on, after which two, and in fine three, are used.

In this manner a survey is taken of the general outline and larger parts in the first instance, and the more minute parts afterwards.

78. The most generally convenient position for the instrument is that which is shown in fig. 37. If a vertical position be desired, it may however be easily obtained. For this purpose the rectangular piece V is drawn out of the bayonet-joint, and the object-tube is directly inserted in the body, so that its axis shall be horizontal and coincident with that of the body R and the eye-tube T. The body is then turned upon the joint c until it is raised into the vertical position. The relative position which the parts then assume is that which is shown in fig. 38.

79. When chemical phenomena are submitted to microscopic examination, and in general when liquids are observed which are liable to evaporation, it is found inconvenient to place the stage under the object-glass, inasmuch as the vapour proceeding from the liquid being more or less condensed upon it, destroys the clearness of the image.

Fig. 38.



Acid vapours sometimes rise from the substances under experiment, which often tarnish the object-glasses, and almost always corrode the metal of the instrument.

In such cases, therefore, it is necessary to provide means to place the liquid under observation in a glass capsule (a watch-glass, for example) above the object-glass, which must consequently be directed upwards, the stage supporting the capsule being over it.

To accomplish this, the rectangular piece V X is turned within the body upon its bayonet-joint through half a circumference, so that the object-tube X is presented vertically upwards, as shown in fig. 39. The arm *e f* carrying the stage *l*, the diaphragm *h* to limit the illumination, and the illuminating reflector or lens *g*, is then fixed upon the tube X; these pieces being severally moveable on the bar *e f* in the manner already described.

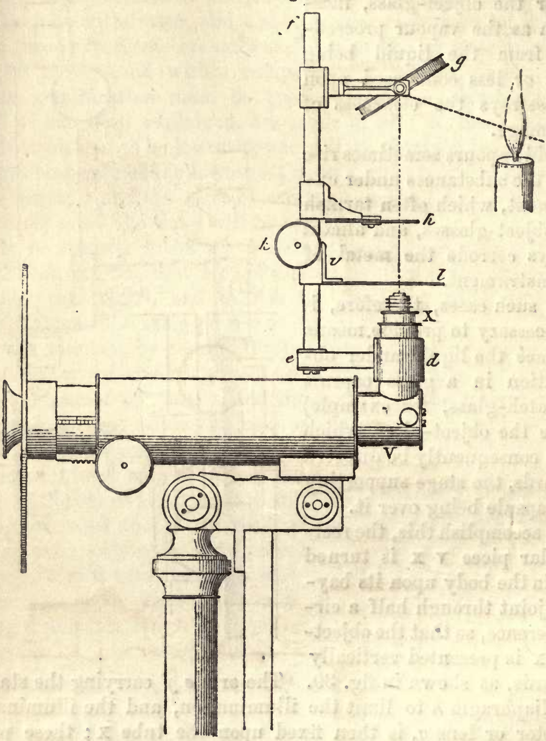
This arrangement is also useful when it is required to observe minute bodies which sink to the bottom of liquids, or animalcules which rarely come near the surface.

In certain cases, also, the circulation of the blood can only be observed with the instrument in this position.

80. It is sometimes desirable to direct the instrument horizontally towards the stage placed vertically. To accomplish this, it is only necessary, after arranging the instrument as shown in fig. 40, to turn the arm E *c* round through an angle of

90°, the pin G being withdrawn, so as to leave the bar D F G with the stage and its appendages free to turn on the joint E with the arm E *c*. The body R and the bar D F G will then be brought

Fig. 39.



into the horizontal position. The stage will then be vertical, and the object will be held in its position by the springs.

The illumination of the object may be produced either by the reflector or lens in the manner already described; or, if they are removed from the bar D F G, the stage may be presented directly to the light of the sun, the clouds, or a candle or lamp.

In some cases, however, when it is necessary to obtain a more intense illumination, an apparatus represented at *s s′* is employed, consisting of two convex lenses placed in the ends of a conical tube which slides upon the bar, by means of a square piece at the end of the arm *t*.

Besides the several motions above described, the body of the instrument has motion in an horizontal plane round the piece *a*,

Fig. 40.

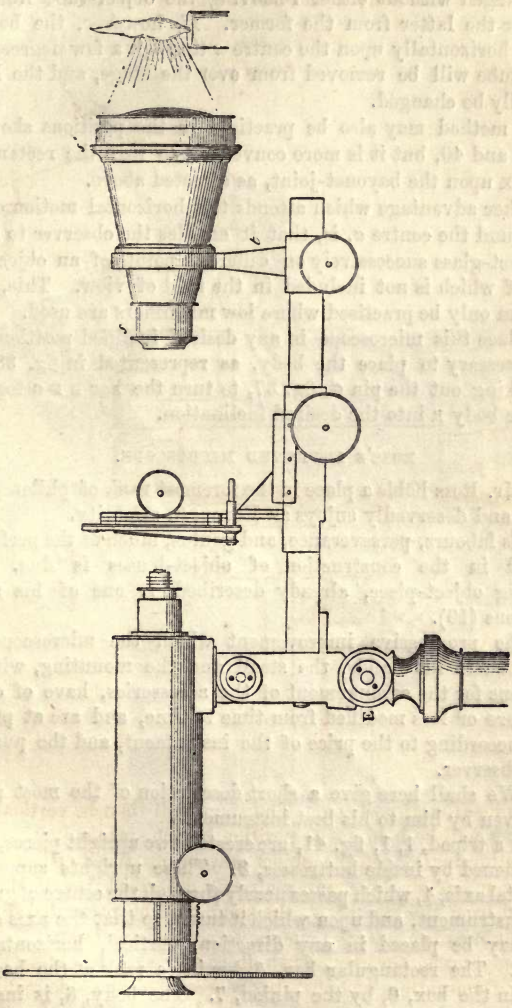


fig. 37, as a centre. This motion is very convenient when the instrument is used in the positions shown in figs. 37, 38, and 39,

for the purpose of changing the angles. In general, and more especially when high powers are used, the object-glasses are so close to the stage, that they cannot be conveniently unscrewed and changed without either removing the object-tube from the stage, or the latter from the former. If, however, the body be turned horizontally upon the centre *a* through a few degrees, the object-tube will be removed from over the stage, and the lenses can easily be changed.

This method may also be practised in the positions shown in figs. 38 and 40, but it is more convenient to turn the rectangular piece Y X upon the bayonet-joint, as directed above.

Another advantage which attends this horizontal motion of the body round the centre *a*, is, that it enables the observer to direct the object-glass successively on different points of an object, the whole of which is not included in the field of view. This, however, can only be practised where low magnifiers are used.

To place this microscope in any desired inclined position, it is only necessary to place the body, as represented in fig. 38, and then taking out the pin G, fig. 37, to turn the bar D F G together with the body R into the desired inclination.

ROSS'S IMPROVED MICROSCOPE.

81. Mr. Ross holds a place in the foremost rank of philosophical artists, and deservedly enjoys an European celebrity.

To his labours, perseverance, and genius, much of the perfection attained in the construction of object-lenses is due. The adjusting object-piece, already described, is one of his recent inventions (19).

In the progressive improvement which the microscope has undergone in his hands, the stand and the mounting, with the provisions for the arrangement of the accessories, have of course been more or less modified from time to time, and are at present varied according to the price of the instrument, and the purposes of the observer.

82. We shall here give a short description of the most recent form given by him to his best instruments.

Upon a tripod, 1, 1, fig. 41, are erected two upright pieces, 2, 2, strengthened by inside buttresses, 3. These uprights support an horizontal axis, 4, which passes nearly through the centre of gravity of the instrument, and upon which it turns, so that the axis of the body may be placed in any direction, vertical, horizontal, or oblique. The rectangular bar, 5, having a rack at the back, is moved in the box, 6, by the pinion, 7. The body, 8, is inserted in a ring at the end of the arm, 9, which latter is fixed upon a pin at the end of the rod, 5, upon which it turns, so as to remove

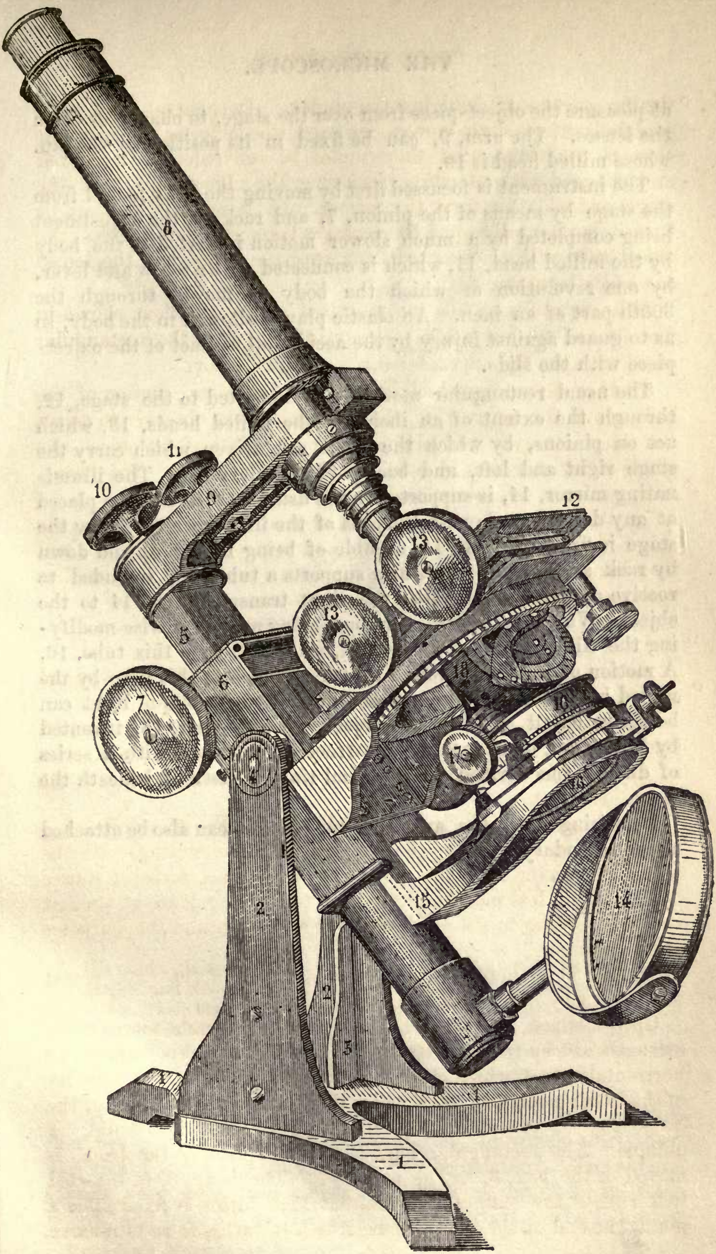


Fig. 41.

at pleasure the object-piece from over the stage, to change or clean the lenses. The arm, 9, can be fixed in its position by the pin, whose milled head is 10.

The instrument is focussed first by moving the body to and from the stage by means of the pinion, 7, and rack, 5, the adjustment being completed by a much slower motion imparted to the body by the milled head, 11, which is connected with a screw and lever, by one revolution of which the body is moved through the 300th part of an inch. An elastic play is allowed to the body, so as to guard against injury by the accidental contact of the object-piece with the slide.

The usual rectangular motions are imparted to the stage, 12, through the extent of an inch, by the milled heads, 13, which act on pinions, by which the racks are driven which carry the stage right and left, and backward and forward. The illuminating mirror, 14, is supported in the usual way, so as to be placed at any desired angle with the axis of the instrument. Below the stage is fixed an arm, 15, capable of being moved up and down by rack and pinion. This arm supports a tube, 16, intended to receive apparatus to modify the light transmitted by 14 to the object. Various apparatus for condensing and otherwise modifying the illumination are provided, which fit into this tube, 16. A motion of revolution round its axis is given to this tube by the milled head, 17. By these means, the effect of oblique light can be shown on all parts of the object. A condenser, 18, invented by Mr. Gillet, of a peculiar construction, provided with a series of diaphragms formed in a conical ring, is inserted beneath the stage.

Polarising apparatus, and other appendages, can also be attached to the secondary stage.

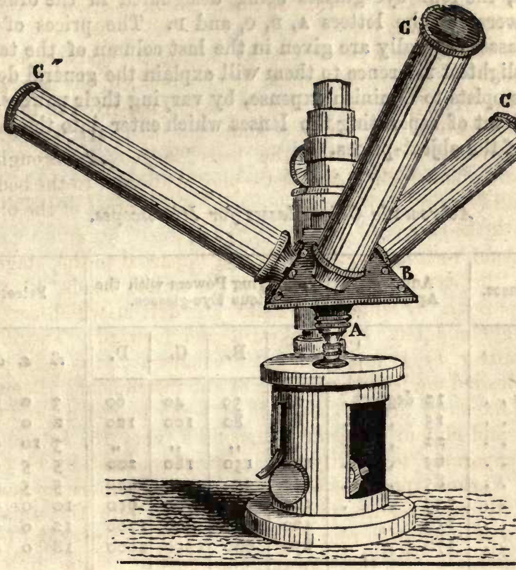


Fig. 45.—NACHET'S TRIPLE MICROSCOPE.

THE MICROSCOPE.

CHAPTER VI.

83. His object-glasses. MESSRS. SMITH AND BECK'S MICROSCOPE : 84. Their largest and most efficient instrument.—85. Their smaller microscope.—86. Their object-glasses.—87. Varley's microscope. M. NACHET'S MICROSCOPE : 88. Their adaptation to medical and chemical purposes.—89. Multiple microscopes.—90. Double microscope.—91. Binocular microscope.—92. Triple and quadruple microscopes.

83. WITH his largest and best instruments, Mr. Ross supplies four eye-glasses and eight object-glasses, by which thirty-two varieties of power and illumination may be obtained. The object-glasses vary from two inches to a 12th of an inch in focal length, and from 12° to 170° in angular aperture. The following

is a tabulated statement of the powers resulting from these combinations, the four eye-glasses being designated in the order of their powers, by the letters A, B, C, and D. The prices of the object-glasses severally are given in the last column of the table, and the slightest reference to them will explain the general desire of microscopists to diminish expense, by varying their powers, by the expedient of separating the lenses which enter into the composition of the object-pieces.

Achromatic Object-glasses for Microscopes.

Object-glasses.	Angular Aperture.	Magnifying Powers with the various Eye-glasses.				Price.		
		A.	B.	C.	D.	£	*s.*	*d.*
2 inches . .	12 degrees .	20	30	40	60	3	0	0
1 ,, . .	15 ,, .	60	80	100	120	2	0	0
1 ,, . .	22 ,, .	,,	,,	,,	,,	3	10	0
$\frac{1}{2}$,, . .	65 ,, .	100	130	180	220	5	5	0
$\frac{1}{4}$,, . .	85 ,, .	220	350	500	620	5	5	0
$\frac{1}{6}$,, . .	135 ,, .	320	510	700	910	10	0	0
$\frac{1}{8}$,, . .	150 ,, .	420	670	900	1200	12	0	0
$\frac{1}{12}$,, . .	170 ,, .	650	900	1250	2000	18	0	0

When angular apertures, so extreme as those indicated in the preceding table, are attempted, it is necessary that the object-lens presented to the pencil diverging from the object, shall be of the meniscus form, the concave side being turned towards the object, for the reasons explained in 19.

Besides the larger class of instruments above described, Mr. Ross constructs microscopes in a variety of other forms, which are placed within the reach of those who do not find it convenient to incur the expense of the larger instrument.

MESSRS. SMITH AND BECK'S MICROSCOPE.

84. The largest and most efficient class of instruments constructed by these artists, do not differ much in their mounting from those of Mr. Ross above described. Like the latter, they are supported by a horizontal axis, between two strong vertical pillars, screwed into a tripod base. The instrument with its appendages, turning on the horizontal axis, can thus be placed at any obliquity whatever with the vertical. The coarse adjustment of this microscope is made by a rack and pinion, by which

the entire body is moved to and from the stage. The object-piece is set in a tube, which moves within the principal tube of the body, the motion being imparted to it by a fine screw with a milled head, which constitutes the fine adjustment. Two different kinds of stage are supplied, one called the lever stage, consisting of three plates of brass, the lowest of which is fixed, and the other two provided with guides and slides, and a lever by which they may be moved, together or separately, in directions at right angles to each other; the other form of stage also has two motions at right angles to each other, one produced by rack and pinion, and the other by a screw whose axis is carried across the stage, and is turned by the left hand, while the rack and pinion is turned by the right hand.

85. Messrs. Smith and Beck also construct other forms of microscope, which, though perfectly efficient, are cheaper and more simple; one of these is represented in fig. 42, p. 17. It is mounted upon a vertical pillar, supported on a tripod T; the body of the microscope plays upon a cradle joint, to which the bent arm U U is attached; the body of the instrument is moved by a rack and pinion in a triangular groove formed in the upper part of this arm; the coarse adjustment is made by the milled heads which move the entire body to and from the stage. In the lower end of the body, a tube is inserted, from which an arm projects, in which a fine screw plays, which is connected with another arm attached to the body of the instrument: by turning the milled head, a slow motion is therefore imparted to the tube thus inserted in the lower extremity of the body. In the end of this tube the object-piece is set, so that the fine adjustment is made by this screw.

To the lower end of the bent arm U U, the stage and its appendages are attached; two motions at right angles to each other are imparted to the stage, by milled heads; the reflector is mounted in the usual way, and provisions are made under the stage, by which achromatic condensers, polarisers, and other apparatus can be applied; the disc of diaphragms is shown at L; it is mounted on a short piece of tube, in which polarising and other apparatus may be inserted.

86. Messrs. Smith and Beck supply with their best microscopes three eye-pieces and five object-pieces, the powers of which, as well as their angles of aperture, are indicated with their prices in the annexed table.

Achromatic Object-glasses for the Microscope.

Focal length.	Linear Magnifying Power nearly.*	With Eye-pieces. No.1.	No.2.	No.3.	Angle of aperture about	Price. £	s.	d.	Lieoerkuhn additional. s.
1½ inch	Draw-tube closed	20	45	80	13 degs.	3	0	0	15
	Add for each inch of tube drawn out	4	6	8					
⅔ inch	Tube closed . .	60	105	180	27 degs.	3	3	0	11
	Add for each inch of tube . . .	7	12	20					
$\frac{4}{10}$ inch	Tube closed . .	120	210	350	55 degs.	5	5	0	10
	Add for each inch of tube . . .	12	20	35					
Ditto	Ditto . . .	do.	do.	do.	65 degs.	6	6	0	10
Ditto	Ditto . . .	do.	do.	do.	75 degs.	7	7	0	10
⅕ inch	Tube closed . .	240	430	720	85 degs.	6	6	0	
	Add for each inch of tube . . .	30	45	80					
Ditto	Ditto . . .	do.	do.	do.	100 degs.	7	7	0	
⅛ inch	Tube closed . .	450	760	1300	100 degs.	8	8	0	
	Add for each inch of tube . . .	40	60	115					
Ditto	Ditto . . .	do.	do.	do.	120 degs.	10	10	0	

* With the ⅔ inch object-glass and the erecting-glasses, employing eye-pieces Nos. 1 and 2, the magnifying power will range from 5 to 150.

Among the accessories of the microscope due to Messrs. Smith and Beck, we must not omit to mention the microscope-table, contrived to facilitate the observations of several persons directed to the same object with the same microscope. Every one who has used this instrument is aware how fatiguing it is to several persons to succeed one another in observing with the same instrument. They are obliged constantly to shift their position, and consequently to make their observation standing. The microscope-table, if it do not entirely remove this inconvenience, greatly diminishes it. It is a circular table, firmly supported on a pillar and claw, capable of being turned with a smooth motion round its centre in its own plane. The observers sitting round it, the microscope is moved successively to the position occupied by each of them by merely turning the table. The best sort of

these tables are made with a plate-glass top, and surrounded by drawers, in which the apparatus can be conveniently assorted.

MR. VARLEY'S MICROSCOPE.

87. This artist has constructed instruments with provisions similar to those already described; they are somewhat different in their form and details. He has, however, recently introduced a microscope, which claims the advantage of enabling the observer to examine living objects, such as animalcules, notwithstanding the inconvenience arising from their restless mobility, causing them continually to escape from the field of view. The stage motion with its appendages, contrived by Mr. Varley, enables the observer, without difficulty, to pursue the object.

He has also contrived a phial-microscope, by which aquatic plants and animals can be conveniently observed.

M. NACHET'S MICROSCOPES.

88. M. Nachet, of Paris, has acquired an European celebrity for the excellence of his instruments, and for the various inventions and improvements in their construction, by which he has extended their utility. He has constructed instruments in various forms, according to the uses to which they are to be applied and their price. For medical and chemical purposes, the body of the microscope slides in a vertical tube, the coarse adjustment being made by a rack and pinion, and the fine by a screw. The stage is firmly fixed under the object-piece, at the top of a hollow cylinder, within which the illuminating apparatus and other appendages are included.

89. One of the most recent novelties due to this eminent artist, is a form of microscope by which two or more observers may, at the same time, view the same object, thus conferring upon the common microscope a part of the advantages which attend the solar microscope. This is accomplished by connecting two or more tubes, each containing its own eye-piece, with a single tube containing an object-piece; it has been already shown that the axis of the tube containing the eye-piece may be placed at any desired inclination, with that which contains the object-piece, by placing in the angle formed by the two tubes, a reflector, or reflecting prism, in such a position, that the pencils of rays proceeding from the object-piece shall be reflected to the eye-piece, without otherwise deranging them. It is evident, therefore, that if the rays proceeding from the object-piece could be at the same time received by two or more reflectors, so placed as to reflect them in two or more directions, they might be transmitted along two or more tubes in these directions to two or more eye-pieces, through which the same object might thus be viewed at

the same time, and through the same object-piece by two or more different observers.

Such is the principle upon which the multocular microscope of M. Nachet is based.

90. A double instrument of this description is shown in fig. 43, where A is the object-piece directed vertically downwards on the stage; above it is a case, containing a triangular prism which is so formed that the light reflected from its left side shall pass along the axis of the right-hand tube, and that reflected from its right side along the axis of the left-hand tube. Observers looking into eye-glasses set in these tubes, would therefore both see the same object in precisely the same manner.

It may perhaps be objected, that the focus which would suit the eye of one observer, would not suit the other; the difference, however, between the focal adjustments of different eyes is always so inconsiderable, that it can be equalised by a small motion given to the tubes carrying the eye-pieces.

Microscopes, as they are usually mounted, reverse the objects, the top appearing at the bottom, the right at the left, and *vice versâ.* This being found inconvenient in instruments used for dissection, where the motion of the hand and the scalpel of the operator would be reversed, expedients are provided by which the

Fig. 43.

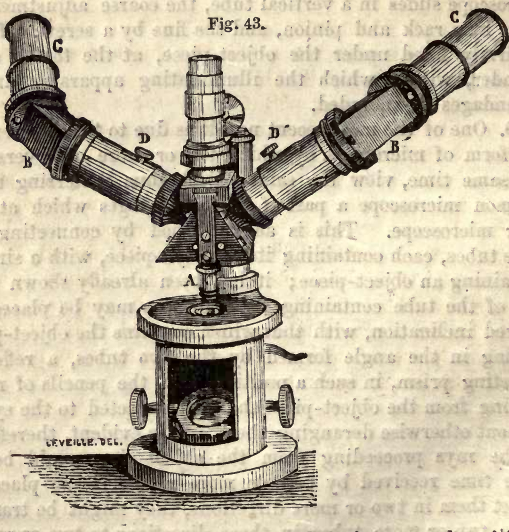
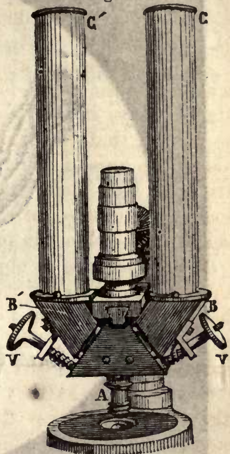


image is redressed, and the object viewed in its natural position. This is accomplished in the microscope represented in fig. 43, by

two prisms fixed at B B′ in the tubes, which are placed at right angles to the lower prism A; by this second reflection, the reversed image of the first reflection, being again reversed, is made to correspond with the natural position of the object.

Fig. 44.



91. An interesting variety of this form of instrument, which may be called a BINOCULAR MICROSCOPE, is shown in fig. 44. In this case the two tubes, B C and B′ C′, containing the two eye-pieces, are placed parallel to each other, the distance between them being regulated by the screws V V; if this distance be so adjusted as to correspond with the distance between the eyes of the same individual, the microscope may be used with both eyes, in the same manner as a double opera-glass. This has the advantage of giving a stronger appearance of relief to the objects viewed, which is especially desirable for a certain class of objects, such as crystals.

92. A triple microscope, upon the principle above described, is shown in fig. 45, p. 81, where A is the object-piece, B the multiple prism, and C, C′ and C″ the three eye-tubes.

A similar instrument, with four eye-tubes, including figures to illustrate the mode of observing with it, is shown in fig. 46, p. 33.

One of the advantages of this class of instruments is, that a professor and one or more of his pupils may view the process of a microscopic dissection which with a common microscope would be impossible, and to which the solar microscope would be inapplicable. Microscopic dissections, in general, can only be exhibited to those who do not execute them, by their ultimate results. Any phenomena which are developed in their progress, can only be made known to others by description; and it is not necessary to say, how imperfect such a mode of communication must be, compared with direct observation.

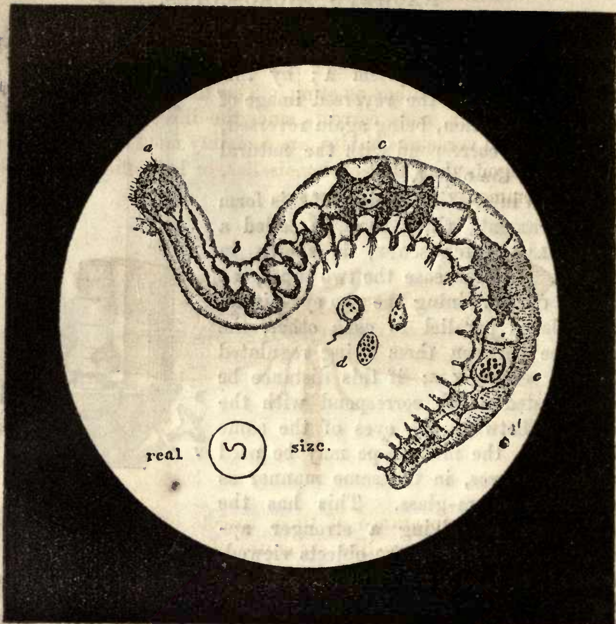


Fig. 5.—MAGNIFIED VIEW OF THE LURCO OR GLUTTON.

MICROSCOPIC OBJECTS.

1. Microscopic objects.—2. The dragon-fly and its larvæ.—3. The satyr. —4. The linceus sphericus.—5. The lurco, or glutton.—6. The water-fly.

1. Having in the preceding Tract explained the structure, application, and use of the microscope in the various forms which have been given to that instrument, we shall here briefly notice a few remarkable microscopic objects, selected chiefly from the Microscopic Cabinet of Mr. Pritchard, illustrated with magnified drawings by the late Dr. Goring.

2. The family Libellulidæ includes an extensive and beautiful group of large insects not sensibly differing in their external form from the ant-lion, already noticed.*

* Instinct and Intelligence, p. 119.

These are popularly known by the names of horse-stingers and dragon-flies. The former name is founded on a vulgar error, since the animal has no sting. The illusion implied by the latter is, however, more correct, since the insects, both in their appearance and voracious habits, are certainly more entitled to the name of dragons than that of demoiselles, or lady-flies, by which they are commonly known in France.

Fig. 1.

The beautiful appearance of these insects on the wing, their varied colours, the gauze-like structure of their wings, and the rapidity of their flight, must have attracted general attention. In hot summer days, they may be seen darting backwards and forwards in the air over standing pools, which supply them abundantly with the insects on which they feed. Their colours are subject to much diversity, the males having an abdomen of leadish blue, while that of the females is a yellowish brown. In some species, the males have a rich bright blue colour, with black wings, while the females are distinguished by a fine green, with colourless wings.

After impregnation, the female hovers over the surface of the water until she selects a place for the deposition of her eggs, which she deposits one by one in the water, beating the surface with her tail while she lays them, until at length they are collected into a mass resembling a bunch of grapes.

The larvæ on issuing from the egg are so minute as to be scarcely perceptible to the naked eye. In some days, however, they attain the length of the tenth of an inch, and cast their skin for the first time. To the naked eye they appear in this state like black spots, to which a tail is attached. When well fed they grow rapidly; and when they have attained the length of about a quarter of an inch, they begin to display their characteristic courage and ferocity, attacking, with open mouth, creatures ten times their own bulk; and, when pressed by hunger, devouring each other.

The magnified drawing of this larva, from which fig. 2 was

Fig. 2.—MAGNIFIED VIEW OF THE LARVA OF A SPECIES OF DRAGON-FLY DRAWN BY DR. GORING.

taken, was made by Dr. Goring, and published with a description

by Mr. Pritchard in the Microscopic Cabinet. The real length of the creature, measured from the extremity of the antennæ to that of the tail, was eight-tenths of an inch. It is represented in the figure, as seen in profile, the breadth of the head and other parts being necessarily foreshortened.

A system of tracheæ, with numerous ramifications, passes along each side of the body from the head to the tail, one of which is seen in the figure. These respiratory apparatus ramify in a beautiful manner in the triple branches of the tail, each of which receives a branch from each trachea.

During its growth the larva casts its skin several times, and the skin which it thus throws off, being translucent, is an interesting and beautiful microscopic object.

The eyes as well in the larva as in the perfect insect are very salient, and from their magnitude and structure form interesting microscopic objects. Like those of some other insects described in a former Tract,* they consist of a multitude of distinct organs of vision, each of which is an hexagonal lens. It was observed by Latreille, that their number increased in proportion to the voracity of the insect. Leuwenhoeck counted 12000 in a single insect. Each hexagon is a convergent lens, which may be converted into a microscope. Each of these lenses is found to produce an inverted image of an object to which it is presented.

3. The object shown in fig. 3, engraved from a drawing by Dr. Goring, and described in the Microscopic Cabinet by Mr. Pritchard, belongs to the class of animalcules denominated by Müller monoculi, from the circumstance of their having a single organ of vision, *a*, placed in the centre of the front of the head. This specimen is called the satyr, and is the amymone satyr of Müller. The figure represents a magnified view of the full-grown insect, seen at the inferior surface of its body as it presents itself to the observer, attached to the inner surface of a vase of water in which it moves. The real length of the animalcule here represented was the 120th of an inch. When they are

Fig. 3.

* "Microscopic Drawing and Engraving," p. 50.

young they are much smaller, and being then perfectly translucent, are highly interesting microscopic objects. They are found in abundance in the months of March and April, at the surface of shallow pools of clear water which contain aquatic plants.

The back of this animalcule is protected by a tender and transparent shell, the belly being naked and membranous. Seen in profile it resembles a tortoise, but, as shown in the figure, it has the form of a horse-shoe. It has four feet, and two antennæ attached to the inferior part of the body, and radiating from a common centre. Placed in the middle of the head, between the two antennæ, *b*, are the mouth and the single eye, *a*, the latter being black, and set in a square orbit of a deep crimson colour. Each of the antennæ has four articulations, and is furnished with bristles at its extremity. The feet, *c c*, are divided at the second joint, and terminate in strong pincers. The peristaltic motion of the alimentary canal can be distinctly perceived with the microscope, by observing the dark lines which run along the body of the animalcule. On each side of this canal are placed the ovaries, *d*, which, when they are fully developed, are distinguished by their dark colour. The satyr swims by sudden impulses, moving the feet rapidly, and sometimes appears to slide along the internal surface of the vase.

4. The animalcule represented in fig. 4, and reproduced from a drawing by Dr. Goring, is the linceus sphericus of Müller, miscalled monoculus minutus by Linnæus, since it has two eyes sufficiently apparent. The figure is reproduced from the Microscopic Cabinet of Mr. Pritchard, where the animalcule is described.

Fig. 4.

The shell or cuirass, which is quite translucent, consists of a single piece, without any perceptible articulation. It possesses, however, sufficient elasticity to allow the animal to open it at will, after the manner of a common mussel. The two edges of the opening are seen in the figure at *a*, the figure being understood to present a profile of the object. The two eyes, *a*, have different magnitudes, and their black colour presents a striking

contrast with the surrounding parts. They are encased in the shell by which they are protected. The beak, *b*, is pointed, and participates in the general convexity of the shell. Under it is placed a second beak-like projection, somewhat shorter, and having three coarse hairs at its extremity, which probably serve the purpose of palpi or feelers. Below this are placed the two antennæ, *c*, each of which is terminated by similar but longer hairs. The false feet or branchiæ, which are four in number and ranged along the edge of the shell, are covered with hairs, and terminate like the antennæ; by their action a rotatory motion is imparted to the animalcule, which is accelerated by the action of the projecting part, *d*, against the water. This part is ciliated on its posterior edge, and armed at its extremity with strong claws. The ovaries, which appear at *e*, have a greenish-blue colour, and the form of a mulberry. The convolutions of the alimentary canal with the food contained in it are visible with the microscope from one extremity to the other.

But the most remarkable organ is a small oval body placed behind the head and shown in the upper part of the figure. This body has a rapid motion of pulsation.

5. These creatures feed upon animalcules, and in their turn become themselves the prey of aquatic larvæ and coleoptera, such as the water-beetles. They are the especial food of the lurco, or glutton (the larva of the naid), a magnified view of which is shown in fig. 5, with several lincei, *c*, visible within it. The young ones are seen playing around the mother, and on the approach of an enemy they rush for protection under her cuirass, which she immediately closes upon them.

6. The crustaceous animalcule represented in B, fig. 1, in its natural size, and in A, fig. 2, magnified, is the four-horned cyclops, or little water-fly; the cyclops quadricornis of Müller, the monoculus quadricornis of Linnæus, and the pediculus aquaticus, or water-louse, of Baker. The figure was drawn by Dr. Goring, and described by Mr. Pritchard in the Microscopic Cabinet.

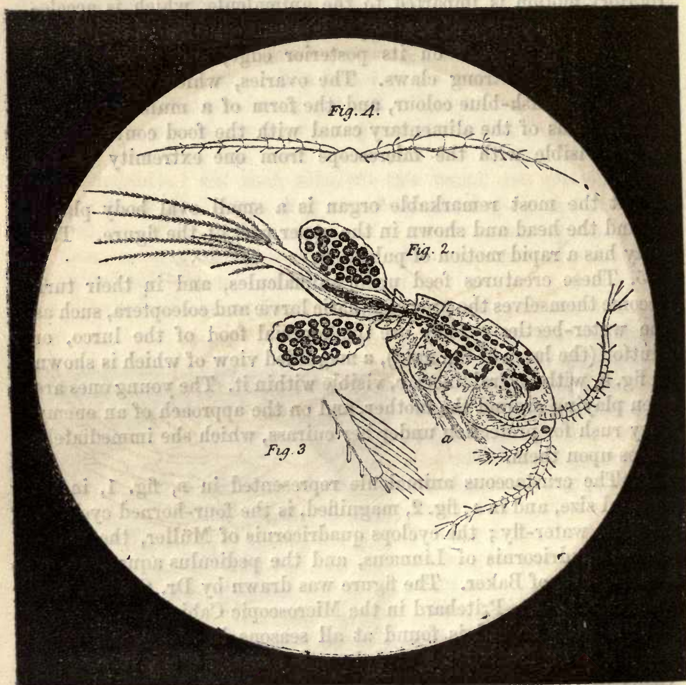
This little animal is found at all seasons in water, but more especially in the months of July and August, when it may be easily taken by a net at the depth of about an inch below the surface.

The body is covered with scales, which have a vertical and lateral motion. Their edges do not meet under the insect, but leave a space for the insertion of the organs of respiration, *a*. The beak is short and pointed, and is a mere prolongation of the first segment of the body. A little above it is inserted in the cuirass a single eye of a crimson colour, so dark as to approach

nearly to black. On each side of the eye are inserted the antennæ, of which there are two pair, the superior being longer than the inferior. They are composed of numerous articulations, from each of which issue two or several hairs. In some species the sexes are distinguished by the form of these appendages, being straight and thicker, with an enlargement towards the middle of their length, in the male, as shown in fig. 4.

These insects move by sudden jumps or plunges, but sometimes creep along the twigs of plants, in which movements they are

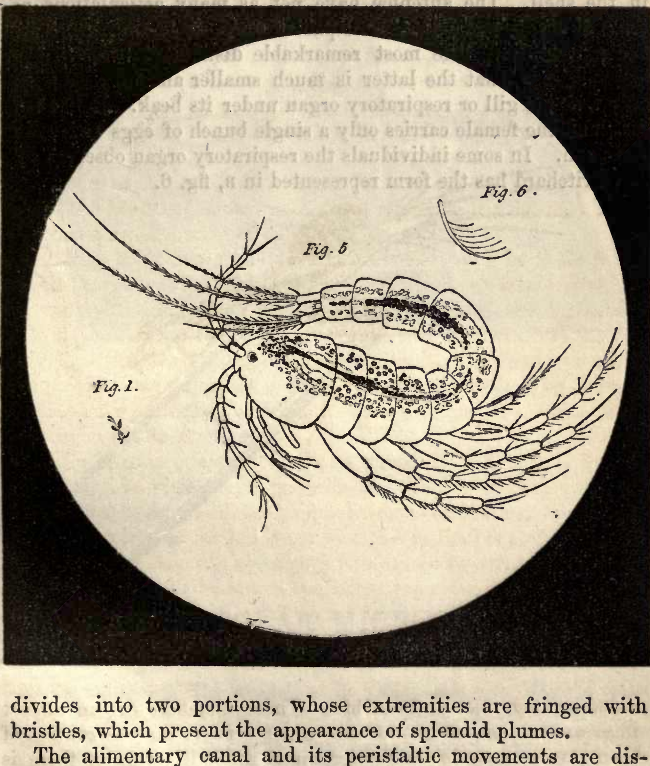
A



aided by their feet or branchiæ. These members are in almost incessant motion, a circumstance which renders the observation of their precise form in the living animal difficult. One of them is represented as seen under a higher magnifying power in A, fig. 3; they are generally transparent, but sometimes have a greenish-blue colour.

The ovaries consist of two sacs, which have the appearance of bunches of grapes attached to either side of the posterior extremity of the body, as shown in A, fig. 2. The eggs are globular, and are enclosed in a transparent membrane. The centre of each egg has an opaque colour, some being green and others red. Their number increases with the age of the female, and when they have attained a sufficient maturity the embryo of the future animal may be seen within them with a magnifier. Mr. Pritchard has distinctly seen these with a single lens with a focal length of about the 25th of an inch. At the extremity of the alimentary canal the tail

B



divides into two portions, whose extremities are fringed with bristles, which present the appearance of splendid plumes.

The alimentary canal and its peristaltic movements are distinctly visible in specimens which are only slightly coloured. Above this canal two others can be observed, through which the eggs are projected to the ovaries at each side of the tail.

The colours of the coat of these insects vary in different individuals, as well as the colours of their ovaries, some being of a greenish-blue, and others red with green ovaries.

Another variety of this, called by Müller the cyclops minutus, or little cyclops, and popularly the jumper, is shown in B, fig. 5, as drawn by Dr. Goring, the animalcule being in a bent position, one of its characteristic attitudes. The real length of this specimen was about the 250th of an inch.

The structure of the coat, or cuirass, is similar to that of the animalcule represented in A, fig. 2, but it has a greater number of segments and a more graceful outline. The single eye is encrusted in the shell. The antennæ have not as many articulations as those of fig. 2, and the inferior pair of palpi is more plumed at the extremities. The most remarkable distinction between the two species is, that the latter is much smaller and supplied with only a single gill or respiratory organ under its beak. It has ten feet, and the female carries only a single bunch of eggs under the abdomen. In some individuals the respiratory organ observed by Mr. Pritchard has the form represented in B, fig. 6.

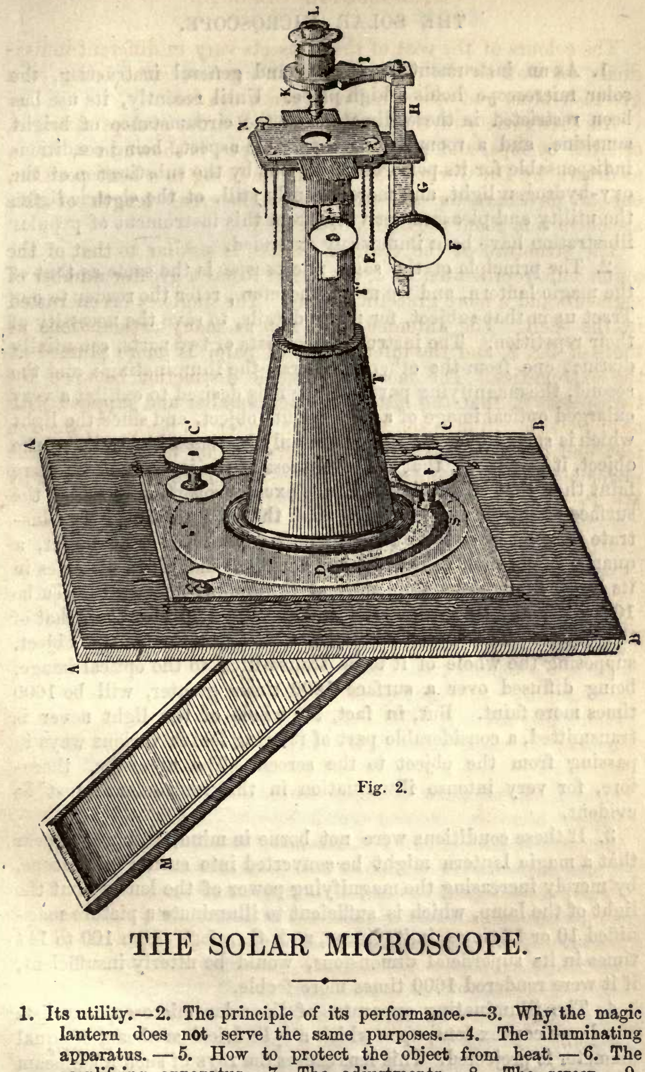


Fig. 2.

THE SOLAR MICROSCOPE.

1. Its utility.—2. The principle of its performance.—3. Why the magic lantern does not serve the same purposes.—4. The illuminating apparatus. — 5. How to protect the object from heat. — 6. The amplifying apparatus.—7. The adjustments.—8. The screen.—9. The reflector.—10. Method of mounting the instrument.—11. Arrangements for the room of exhibition.—12. Preliminary adjustments. —13. The oxy-hydrogen and electric microscopes.

1. As an instrument for popular and general instruction, the solar microscope holds a high place. Until recently, its use has been restricted in these climates, by the circumstance of bright sunshine, and a room having a suitable aspect, being conditions indispensable for its performance. But by the substitution of the oxy-hydrogen light, and more recently still, of the electric light, the utility and pleasure derivable from this instrument of popular illustration have been immensely extended.

2. The principle of the solar microscope is the same as that of the magic lantern, and we must, therefore, refer the reader to our Tract upon that subject, for many details, to save the necessity of their repetition. The instrument consists of two parts, essentially distinct one from the other: the first, the illuminating; and the second, the magnifying part. Since it is desired to exhibit a very enlarged optical image of a very minute object, and since the light which is spread over the image can only be that which falls on the object, it is evident, that the brightness of the image will be more faint than that of the object, in the exact proportion in which the surface of the former is greater than that of the latter. To illustrate this, let us suppose that the object exhibited is an insect, a quarter of an inch in length, and that it is magnified 40 times in its linear dimensions, the length of the optical image will then be 10 inches, and its surface will be 1600 times greater than that of the object. The light, therefore, which illuminates the object, supposing the whole of it to be transmitted to the optical image, being diffused over a surface 1600 times greater, will be 1600 times more faint. But, in fact, the whole of the light never is transmitted, a considerable part of it being lost in various ways in passing from the object to the screen. The necessity, therefore, for very intense illumination in this instrument must be evident.

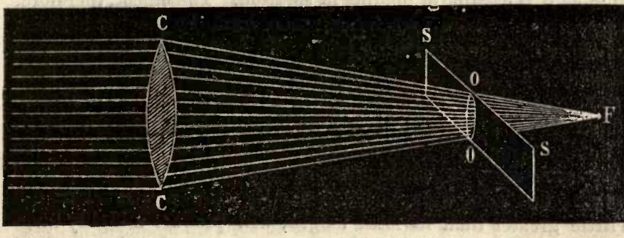
3. If these conditions were not borne in mind, it might appear that a magic lantern might be converted into such a microscope, by merely increasing the magnifying power of the lenses; but the light of the lamp, which is sufficient to illuminate a picture magnified 10 or 12 times in its linear, and, therefore, from 100 to 144 times in its superficial dimensions, would be utterly insufficient, if it were rendered 1600 times more feeble.

4. The illuminating apparatus of the solar microscope consists of a large convex lens, upon which a cylindrical sunbeam of equal diameter is projected. This lens causes the rays of such a sunbeam to converge to a point, and they are received upon the object to be exhibited before their convergence to a focus, and at such a distance from the focus, that the entire object shall be illuminated by them. In fact, the rays may be considered as forming a cone

which is cut at right angles to its axis by the slider upon which the object is fixed.

Let C C, fig. 1, be the condensing lens; let F be the focus to which the rays would be made to converge, but being intercepted

Fig. 1.



by the slider S S, they are collected upon the small circular opening O O in the slider, and in this circular opening the small microscopic object to be exhibited is mounted between two thin plates of glass.

Now, it is evident, that the intensity of the light thus projected upon the object will be greater than that with which it would be illuminated without the interposition of the lens C C, in the exact proportion of the surface of the lens C C to the surface of the circular opening O O. Thus, for example, if the diameter of the lens C C be 5 inches, and the diameter of the opening O O half an inch, the diameter of the lens will be 10 times, and, therefore, its surface 100 times greater than that of the opening O O. In that case the object would be illuminated with a light just 100 times more brilliant than if the sun's light fell directly upon it, without passing through the lens C C.

It is found convenient in some cases to condense the light by means of two lenses. The cone of rays proceeding from C C might be received upon another condensing lens, by which its convergence might be increased. The advantage of this arrangement is that the distance of the object from C C, and therefore the length of the microscope, is rendered less than it otherwise would be.

5. There is, however, one practical inconvenience to be guarded against in this arrangement. The lens C C, which condenses the sun's light upon the object, also condenses its heat, and if the same object be exposed in the instrument for any considerable time, it would thus be injured or destroyed. This inconvenience may be obviated by the interposition of certain media, which, while they are pervious to the sun's light, are impervious to its heat; such media are said to be athermanous.*

* From the Greek negative *α* (a) and *θέρμη* (thĕrmè) heat.

By the interposition of such a medium, the object may be prevented from receiving any increased temperature whatever.

It happens that water, which is the most convenient medium for this purpose, is very imperfectly pervious to heat, and is rendered almost completely athermanous by dissolving in it as much alum as it is capable of holding in solution. The object, therefore, is perfectly protected from the effects of heat, by placing between the slider and the condensing lens a cell, consisting of two parallel plates of glass, fixed at about an inch asunder, and filled with such a saturated solution of alum. The light intercepted by this is altogether inconsiderable, while the whole of the heat is stopped by it.

6. The magnifying part of the solar microscope consists of an achromatic lens, or combination of lenses, of very short focal length; this being brought before the object, at a distance from it a little greater than its focal length, will produce a highly magnified optical image of the object, upon a screen placed at a proper distance before it.

In the case of the magic lantern, it is not indispensable to incur the expense of achromatic lenses, and even the expedients to correct the spherical aberration are but little attended to. The magnifying powers used in that instrument not being great, and the objects exhibited not requiring extreme accuracy of delineation, the expense which would be incurred in producing large lenses free from the aberrations is not necessary. But in the case of microscopic objects, where great magnifying powers are applied, lenses in which the aberrations are not corrected would produce images so confused and indistinct as to be altogether useless. Achromatic combinations, therefore, in which the spherical aberrations are also corrected, are in this case indispensable.

As in the magic lantern, the same lenses may be applied, so as to produce different magnifying effects. If the distance of the lenses from the object were so great as twice their focal length, the image would be projected upon the screen at a distance in front of the lens also equal to twice its focal length, and would in that case be exactly equal to the object, and consequently there would be no amplification at all. As the lenses, however, are moved nearer to the object, the distance at which the image would be formed and its magnitude would be increased, and this increase would go on without practical limit, until the distance of the lens from the object would become equal to its focal length, in which case the image, having been enlarged beyond bounds, would altogether disappear.

In practice, therefore, the focus of the lens is brought to such a distance from the object, that the image upon the screen shall have a magnitude sufficient for all the purposes of exhibition. It

is not desirable, however, in any case, to push the amplifying power of the instrument too far, because the illumination of the image in that case becomes inconveniently faint; and if there be any causes of aberration uncorrected in the lenses, whether spherical or chromatic, their effects will be rendered more apparent.

7. In the mounting of the instrument, provisions are necessary for varying, within certain limits, the distance of the object, as well from the illuminating as from the amplifying lenses. If the object be very minute, it is necessary that it should be illuminated with proportionate intensity; and, therefore, that it should be moved very near to the focus of the illuminating lens, C C. If it be larger, this position would, however, be unsuitable, inasmuch as the light would be collected upon a small part of it, to the exclusion of the remainder. In that case, therefore, the object must be brought farther in advance of the focus, F, of the illuminating lens, so as to intersect the cone at a point of greater section, and thus to receive a light which, though less intense, will be diffused over its entire surface.

The amplification required will be greater in proportion as the object is smaller. For very minute objects, therefore, the amplifying lens must be brought nearer to the object, and the screen must be removed farther from it, while for larger objects, the arrangement would be the reverse.

8. All that has been said on the subject of the screen in the case of the magic lantern will be applicable to the solar microscope, except that, in this case, the method of showing the object through a transparent screen is objectionable, because of the light which is lost by it, and for other reasons; and, besides, it is useless, that method of exhibition being adapted only for phantasmagoria, and other similar subjects of amusement.

9. In what has been explained above, it has been assumed that a beam of solar light is thrown upon the condensing lens C C, in the direction of its axis. Now it is evident that it could never happen that the natural direction of the sun's rays would coincide with that of the axis of the tube of the microscope; for, that axis being necessarily horizontal, or nearly so, the sun to throw its rays parallel to it should be in the horizon. Some expedient, therefore, is necessary, by which the direction of a sunbeam can be changed at will, and thrown along the axis of the tube.

The obvious method of accomplishing this is by means of a plate of common looking-glass; such a plate being conveniently mounted in front of the condensing lens, may always have such a position given to it that it will reflect the sunbeam which will fall upon it in the direction of the axis of the tube.

But since, by reason of its diurnal motion, the sun changes its

position in the heavens from minute to minute, the position of the reflector, which at one time would throw the light in the proper direction, would cease to do so after the lapse of a short interval. A proper provision must be made, therefore, by which the position of the reflector may be changed from time to time with the motion of the sun in the firmament, so that it shall always reflect the light in a proper direction.

10. A perspective view of the solar microscope, mounted in the most efficient manner, is given in fig. 2; but the principle of its performance will be more easily understood by reference to the sectional diagram in fig. 3, where C C is the condensing lens, H H the mirror which receives the sun's light, and reflects it in the direction of the axis of the tube. This mirror turns on a hinge, by which it may be inclined at any desired angle to the axis of the tube; and a provision is also made by which it can be turned round the axis, so that its plane may be presented in any desired direction to the sun: a smaller condensing lens is interposed, upon which the rays, converging from C C, are received, and by which, with increased convergence, they are projected upon the opening O O in the slider S S, in which the object is mounted.

The tube in which the slider S S is inserted, and which carries the smaller condenser, slides within another tube, in the end of which the greater condenser C C is set. By this arrangement, the section of the cone of light, which falls upon the opening O O, may be varied, according to the magnitude of the object.

The amplifying lens, or lenses, L L, are conveniently mounted in a tube, which can be moved within certain limits to or from the object, so as to accommodate the focus to the position of the screen I I, upon which the image is projected.

After these explanations, the reader will have no difficulty in comprehending the instrument, as shown in perspective in fig. 2.

A board, A A B B, is pierced by a large circular aperture, the diameter of which is a little greater than that of the larger condensing lens; a square brass plate, *a a b b*, to which the microscope is attached, is screwed upon this board in such a position, that the condensing lens shall be concentric with the hole in it, and, consequently, that the axis of the instrument shall be at right angles to the board.

The plane mirror M, by which the light of the sun is reflected along the axis of the instrument, is mounted outside the board A A B B, moving on a hinge, as already described; and screws are provided at C C′, by means of which its inclination to the axis of the microscope can be varied at pleasure, and also by which it can be turned round the axis, the screw which governs its motion moving on the circular opening S D. By these means, whatever

be the position of the sun in the heavens, such a position can always be given to the plane of the mirror, that the light may be reflected along the axis of the microscope.

The great condensing lens is set in the larger end of the conical tube T, and the lesser in the end of the cylindrical tube T′; the latter tube being moved within the former by an adjusting screw, which appears at its side. By the second condensing lens, the light is collected upon the opening in the slide, which is held between two plates N, pressed together by spiral springs.

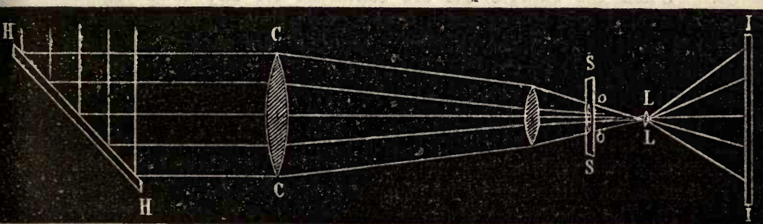
The tube T′ consists of two parts, one moving within the other, like those of the telescope.

The amplifying lenses are mounted in a brass ring, K, carried by the upright piece, I, so that its optical axis shall coincide with that of the illuminating apparatus. This optical part can be moved to and from the object, by means of a rack and pinion, F, attached to the piece H, which slides in the box G.

The structure and principle of the instrument being understood, it only remains to explain the method of using it.

11. The room in which the operations are conducted should have sufficient depth to allow the space between the microscope and the screen, which is necessary for the formation of an image of the required magnitude. This space will vary with the magnifying power required, but in general 10 or 12 feet beyond the nozzle of the instrument is sufficient. The room should be rendered as dark as possible, to give effect to the image, which, however well

Fig. 2.



illuminated, is always incomparably less bright than would be objects receiving the light of day. The window-shutters should therefore be carefully closed, and all the interstices between them stopped. If the room be provided with window-curtains, they should be let down and carefully drawn. In a word, every means should be adopted to exclude all light, except that which may enter through the microscope.

An opening being provided in a convenient position in one of the window-shutters, corresponding in magnitude with the aperture in the board AA BB, the latter is screwed upon the window-shutter, so that the two openings shall coincide. The mirror M will then be outside the window-shutter, while the instrument and its appendages will be inside. The window selected should, of course, be one having such an exposure that the sun's rays can be reflected by the mirror in the direction of the axis of the tube.

12. To adjust the instrument, remove the piece N, which supports the slider, so that the light may pass unobstructed to the amplifying lens. By varying the position of the reflector M, by means of the milled heads C C′, a position will be found in which a uniformly illuminated disc will appear on the screen; this disc may be rendered more clear and distinct by adjusting the instrument by means of the rack and pinion attached to the tube.

When these preliminary adjustments are made, the piece N is replaced, and an object inserted in it; the instrument being then more exactly focussed, a distinct image of the object, upon a large scale, will be seen on the screen.

The management of the instrument will vary with the nature of the object. If it be a very transparent one, a strong light thrown upon it would cause it almost to disappear. The light, therefore, in such case, must be so regulated as to produce the image in the most favourable manner, which may always easily be accomplished by moving the tube T′ in and out of the tube T, until the desired result is obtained.

When the experiments are continued for any considerable interval, it will be necessary, from time to time, to accommodate the reflector M to the shifting position of the sun, which may always be done by the milled-heads C C′. This adjustment, however, might be superseded by mounting the mirror M upon an apparatus called a Heliostat, the effect of which is, to make the mirror move with the sun, by means of clock-work. Such an apparatus, however, is expensive, and the adjustment above described is attended with no great inconvenience or difficulty.

13. The substitution of the oxy-hydrogen, or electric light, for the sun in this most instructive instrument, renders those who use it, however, altogether independent of the sun, so that it can be used for a night as well as a day exhibition. Since the method of applying to it the electric light has been already described very fully in our Tract upon the Magic Lantern, the explanation need not be reproduced here.

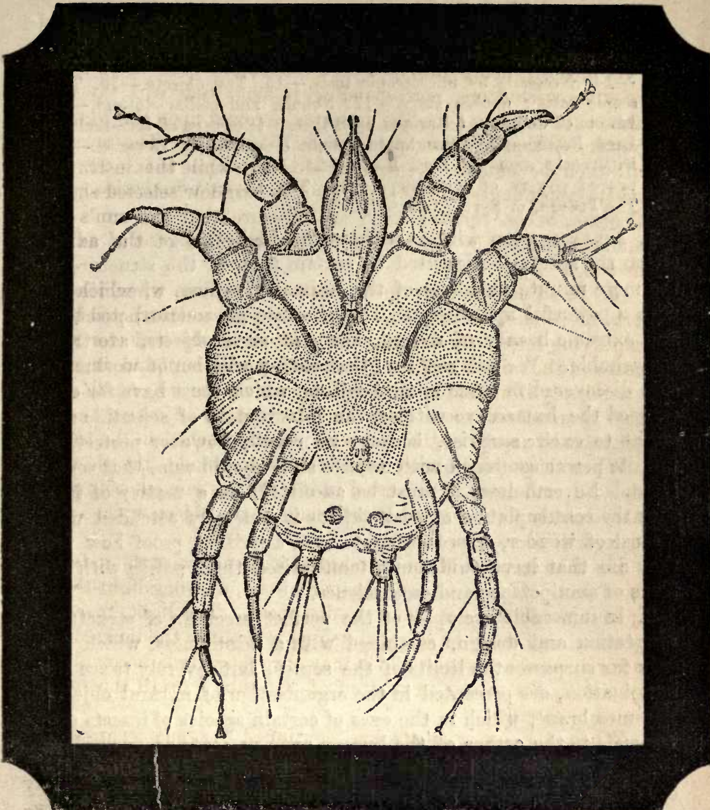


Fig. 37.—VIEW OF THE MANGE INSECT OF THE HORSE, MAGNIFIED 150 TIMES IN ITS LINEAR AND THEREFORE 22500 TIMES IN ITS SUPERFICIAL DIMENSIONS.

MICROSCOPIC DRAWING & ENGRAVING.

CHAPTER I.

1. Beautiful precision of the minute structure of natural objects.—2. Cornea of a fly's eye.—3. Number of eyes of different insects.—4. Astonishing precision of artificial objects.—5. Demand for such objects by Microscopists.—6. Classes of such artificial objects.—7. Microscopic scales.—8. Method of engraving them.—9. Measurement of microscopic objects with them.—10. Their minuteness.—11. Scales

of Mr. Froment.—12. Rectangular scales.—13. Micrometric threads.—14. Necessity for microscopic tests.—15. Test-objects.—16. Telescopic tests; double stars.—17. Nebulæ and stellar-clusters.—18. Effects of different telescopes upon them: telescopes of Herschel and Lord Rosse.—19. Remarkable nebulæ described by Herschel.—20. Differently seen by Lord Rosse.—21. Microscopic tests.—22. Improved powers of microscope.—23. The Lepisma-Saccharina.—24. The Podura, or Spring-tail.

1. No person can witness without the highest degree of admiration the spectacle presented by certain parts of the structure of the more minute members of the animal kingdom, when viewed with a powerful microscope. The absolute geometrical precision and extreme beauty of design shown in such objects, are truly remarkable. We will not say, that such perfection of workmanship discovered in these minute objects, which must have for ever escaped the human eye without the intervention of scientific aid, ought to excite surprise, because no result, however perfect, of infinite power combined with infinite skill should raise that sentiment. Nevertheless, it must be admitted, as a matter of fact, that the contemplation of such objects is generally attended with a sense of wonder, approaching to awe, a striking proof how few they are that have sufficiently familiarised their minds with the ideas of omnipotence and omniscience.

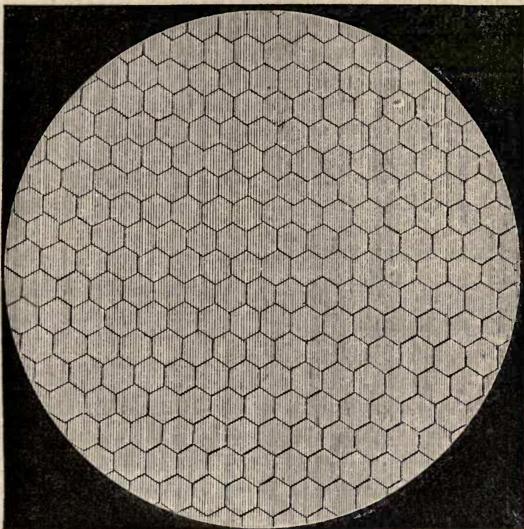
2. Innumerable examples of the perfect precision of structure, adaptation and design, combined with a minuteness, which not only far surpasses the limits of the senses, but severely taxes the imagination, are presented in the organisation of natural objects. The membrane, which in the eyes of certain species of insects corresponds to the cornea of the human eye, presents an example of this. A very exact notion of this membrane, as it exists in the eye of the common house-fly, may be obtained by stretching a piece of bobbin-net over the surface of a billiard-ball: the ball with its reticulated hexagonal coating will then be a very precise model of part of the eye of the insect, upon a prodigiously magnified scale.

We have given in fig. 1 an engraving of this membrane, taken from a microscopic drawing, magnified 100 times in its linear, and therefore 10000 times in its superficial dimensions.

3. Each hexagon, as shown in the figure, is the cornea of a separate eye, having behind it the proper optical apparatus to produce the sense of vision. But it is more particularly to the minuteness of these beautifully precise hexagonal eyes, that I desire at present to direct attention. That minuteness will be most strikingly manifested by stating the number of these eyes with which different classes of insects are provided. According to the observations of various eminent naturalists, such as Swammerdam,

Leuwenhoeck, Barter, Reaumur, Lyonnet, Paget, Müller, Strauss,

Fig. 1.



Dugès, Kirby, &c., the following are the number of eyes in certain species :—

	Number of eyes.		Number of eyes.
The Ant and the Zenos	50	The Cosus Ligniperda .	11300
The Sphinx . .	1300	The Dragon Fly . .	12544
The common Fly . .	4000	The Butterfly . .	17355
The Silkworm . .	6236	The Mordella . .	25088
The Cockchaffer . .	8820		

4. But if the perfection found in the most minute workmanship of nature excite our admiration, how much more must we admire and wonder at the approaches which have been made to a similar degree of precision and perfection by the comparatively feeble and imperfect agency of the human hand. We propose in the present article to call the attention of our readers to some striking examples of such skill and address, with which the general public is not already familiar.

5. The improvements which have been made within the last quarter of a century, in the construction of microscopes, has created a demand for a class of drawings and engravings of a degree of minuteness approaching to that of the objects to which the researches of observers have been addressed. This

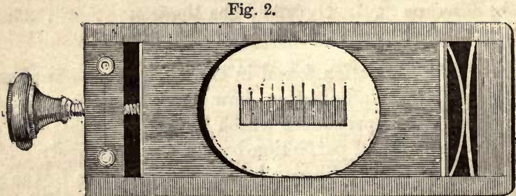
demand of Science upon Art has been adequately and admirably responded to.

6. Mechanism has been invented, by which minute tracings are made by a diamond point on the surface of glass; such tracings being adapted to serve three distinct purposes:—1st. As standard measures of microscopic objects by superposition on them, just as ordinary lengths and breadths are determined by the application of the standard measure of yards, feet, and inches; 2ndly, To serve as tests of the degree of excellence attained in the contruction of microscopes, and as means of comparing the relative excellence of different microscopes, by observing the degrees of distinctness with which they enable the observer to see such minute tracings; and, 3rdly, to serve for the production of microscopic engravings on its proper scale of any desired design.

This last process cannot be said to have been applied hitherto to any useful purpose other than the exhibition of an artistic *tour de force*, being, so far as relates to its means of execution, by far more difficult and ingenious than either of the former.

7. Microscopic objects are measured by divided scales of known dimensions; their lengths and breadths being ascertained by the number of divisions of the scales on which they are placed, included between their limits or within their contour. Such scales, like larger measures, vary with the magnitude of the objects to which they are to be applied, but, even when largest in their divisions, are still very minute. They are generally traced upon small oblong slips of glass, the divisions being marked by fine parallel lines, every fifth division being a little longer than the intermediate ones, and every tenth still longer, as is shown on a greatly magnified scale in fig. 2.

Fig. 2.

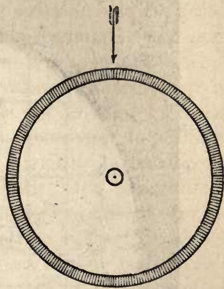


8. The slip of glass upon which the scale is engraved is usually set in a brass framing, in which it is capable of sliding longitudinally, being pressed forwards in one direction by a fine screw, and in the other direction by the action of springs.

The diamond point by which the divisions are traced, is urged upon the glass, with a regulated pressure, so as to make traces so

even and uniform that no irregularity in their edges is discoverable by any microscopic power to which they are submitted. In the process of tracing the divisions, the point is moved over the glass, the latter being fixed, or the glass moved under the point by means of a very fine screw, called a micrometer screw, the magnitude of the thread of which is exactly known. The head of this screw is a metallic disc, fig. 3; the circumference of which is divided into from 200 to 400 equal parts, or even into a still greater number.

Fig. 3.



Let us suppose, then, the screw to be so fine that there are 50 threads to an inch, and the circumference of its head is divided into 100 parts; one revolution of the head will therefore move the screw and the diamond point upon which it acts through the one-fiftieth part of an inch. But if a fixed index be directed to the circumference of the head, so that the motion of the head through one division can be observed, such motion will move the diamond point through the 1-5000th of an inch.

The cutter, after tracing each division, is raised from the glass, while the diamond point is pushed forward by the screw to the position necessary to engrave the next division of the scale, and proper mechanism limits the motion of the screw, so as to regulate the relative lengths of the divisions of the scale in the manner already explained.

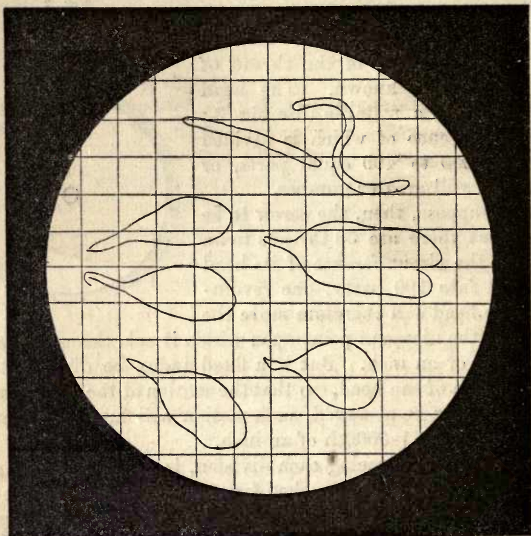
9. A scale thus engraved, being viewed with a microscope whose magnifying power is proportionate to its minuteness, the divisions are rendered as distinctly visible as those of an ordinary rule are to the naked eye, and if the object to be measured be laid upon the glass its dimensions may be ascertained, as those of an object of ordinary size would be by a common rule.

10. These scales vary in the magnitude of their divisions, according to the magnitude of the objects which they are intended to measure. On those which have the largest divisions, an inch is divided into 500 parts; scales, however, are furnished by the opticians for microscopes in which an inch is divided into 2500 parts.

11. However minute such scales may seem, they are by no means the most minute that have been executed. Mr. Froment, whose apparatus for the division of astronomical instruments is well known, has supplied me with a scale in which a millimètre is divided into 1000 equal parts. Each division of this scale is, therefore, only the 1-25000th part of an inch.

12. Scales are sometimes engraved so as to indicate at once the dimensions of an object in length and breadth, by lines dividing

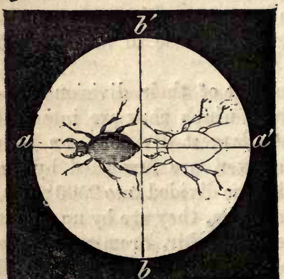
Fig. 4.



the glass in directions at right angles one to the other, as shown in fig. 4, upon a greatly magnified scale.

13. The dimensions of a minute object are sometimes ascertained by a somewhat different expedient.

Fig. 5.



Let two lines, *a a′* and *b b′*, fig. 5, intersecting at right angles, be engraved upon a slip of glass, which can be inserted into the tube of a microscope, as shown in figures 6 and 7, through an opening in the side, which can be closed when such measurement is not required. These engraved lines, when the microscope is properly adjusted, will be seen like two fine threads projected on the object, as shown in fig. 5.

Arrangements are made by which, while the object is fixed,

the glass upon which the lines *a a′* and *b b′* are engraved, can be moved by a fine micrometer screw until the line *b b′* shall pass

Fig. 6.

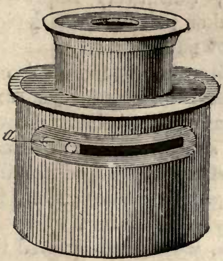
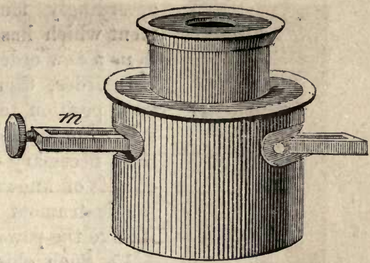


Fig. 7.



successively through the two extremities of the object, or the same purpose will be served, if, while the glass remains at rest, the stage which supports the object be similarly moved.

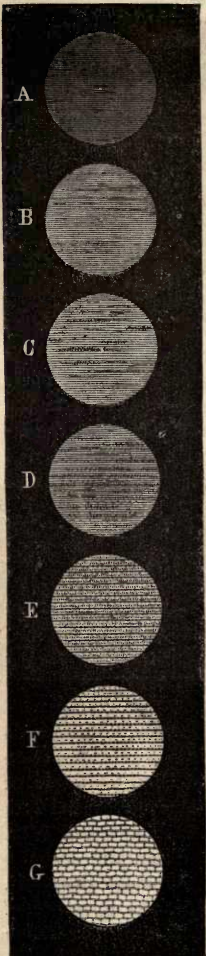
The number of threads of the screw to an inch being known, the number of revolutions and parts of revolutions of the screw necessary to make the line pass from one extremity to another, will give the length of the object, and a like process will determine its breadth.

In the application of such scales to microscopic measurements, various practical precautions and expedients are necessary, which will be fully explained in our Tract on the Microscope.

14. Independently of being provided with means such as have been described above, for ascertaining the dimensions of objects, the advanced state of science renders it indispensable that the observer should possess means of testing the power of his instrument; without such means, he can never be sure that the appearance of the object, as presented by his microscope, corresponds with its real structure, or that important details of that structure may not escape his observation. A more striking example of this cannot be presented than one which was given by the late Dr. Goring, who showed that a particle of the dust taken from the wing of a certain species of butterfly, called the Morpho Menelaus, exhibited the seven different appearances shown in fig. 8; when viewed with the same microscope, the aperture of the object-glass and, consequently, the brightness of the image only being varied. It will be seen that details of structure are rendered apparent in G, where the aperture is greatest, which are very imperfectly shown in F, and not at all in those in which the aperture was still more limited.

If, therefore, the observer were only supplied with a microscope, such as would have shown the object as exhibited at D, he would evidently have formed a very incorrect notion of its structure ; and it is accordingly found, that every improvement which has taken place has disclosed to us a new order of natural facts.

Fig. 8.



In order, therefore, to put the observer in a position to ascertain how far he can rely upon the indications of his instrument, it is necessary to supply him with some objects of known structure, whose details the instrument ought to make visible if it have the power which it claims.

15. Such objects, which have proved to be eminently useful in microscopic researches, and highly conducive to the progress of science, are called TEST-OBJECTS.

16. In the case of the telescope applied to astronomical researches, similar tests of efficiency are found in countless numbers in the heavens. Double, triple, and multiple stars are the most obvious examples of these. Such objects, as is well known, appear when viewed with the naked eye, or even with ordinary telescopes, as single stars; but when instruments of superior power are directed to them they are RESOLVED, as it is called, and seen as what in fact they are, two or more minute stellar points in such close proximity, that the space between them is too small to affect the eye in a sensible manner, unless when magnified by artificial means.

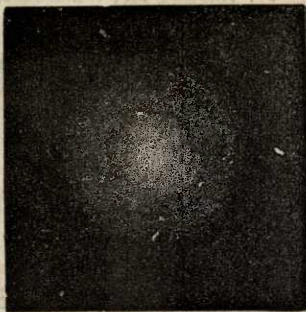
17. Nebulæ supply another order of telescopic test-objects. These appear, even when viewed with telescopes of considerable power, as small patches of whitish, cloudy light, of greater or less magnitude, a character from which they have received their name.

Such an object is represented, for example, in fig. 9.

When, however, a telescope of higher power is directed upon the same object, it will assume such an appearance as is shown

in fig. 10, a faint and rather indistinct indication of minute stars being perceptible; but when a still higher power is brought to bear upon it, the object will be seen as what it really is, a dense mass consisting of countless numbers of separate stars, as shown in fig. 11.

Fig. 9.



18. Different nebulæ require telescopes of different powers, and many have never been yet resolved, even by the greatest powers that scientific art has yet produced. In proportion, however, as the telescopic power has been increased, more and more of these objects have been resolved. A remarkable illustration of this state of progressive discovery is supplied in the case of a well-known nebula, first observed and drawn by Sir John Herschel, as seen in a twenty-foot reflector. Sir John

Fig. 10.

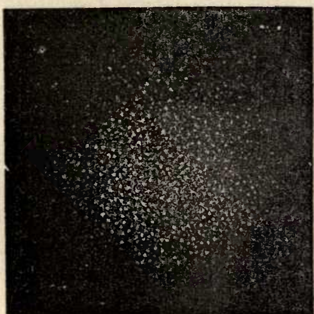


Fig. 11.

describes it as an object shaped like a dumb-bell, double-headed shot, or hour-glass; the elliptic outline being filled up by a more feeble and nebulous light, as shown in fig. 12, copied from the drawing of Sir John Herschel.

Such was the form and character assigned to this object until Lord Rosse had constructed larger and more powerful instruments, and when he directed upon it a twenty-seven foot reflector with three feet aperture, it assumed the appearance shown in fig. 13, where a faint indication of stars can be seen; subsequently,

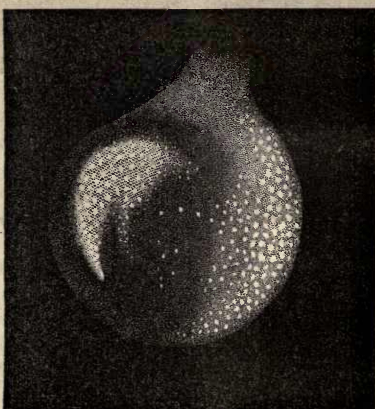
however, when he examined the same object with his great fifty-three foot telescope, having six feet aperture, it assumed the appearance shown in fig. 14.

19. Another very remarkable example of the change of appear-

Fig. 12.

ance produced in one of these wonderful objects, is presented in the case of a nebula first observed by Sir Wm. Herschel, and

Fig. 13.



described by him as a bright round nebula, surrounded by a halo or glory, and attended by a much smaller companion. Sir John

Herschel observed the same object, and discovered in it a very remarkable feature, which the telescope of his father had failed to disclose. This object, as drawn by Sir John Herschel, is shown in fig. 15. The separation in what Sir William Herschel called a

Fig. 14.

halo or glory, and what Sir John Herschel calls a ring, was the remarkable character which Sir John discovered. Sir John conjectured, from the general appearance of the object, that the central round nebula is a globular mass of stars, too distant to admit of being resolved by his telescope, and that what his father called a glory, is an annular mass of stars surrounding the former and split in the direction of its plane, so as to produce the appearance shown in the upper part of the figure.

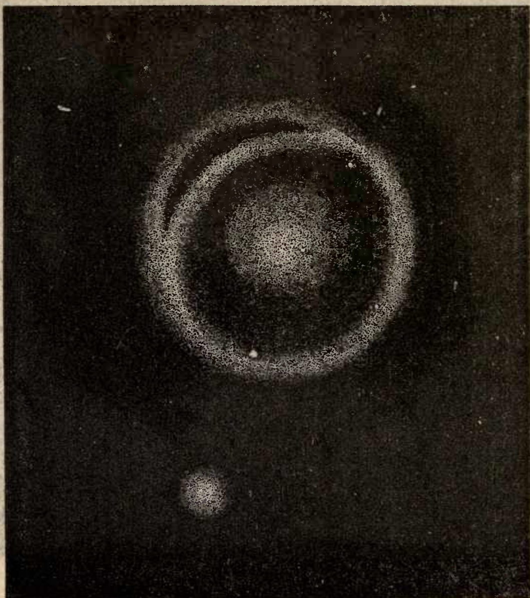
Sir John conjectured that such stellar masses might have some analogy to the mass of stars which forms the milky way, and of which our sun is an individual unit.

20. How completely these speculations, ingenious as they were, were scattered to the winds, by bringing to bear on the same object a higher telescopic power, will be apparent by inspecting

fig. 16, in which the same object is shown as it was afterwards seen with the great telescope of Lord Rosse.

Lord Rosse thinks that the brilliant convolutions of the spiral shown in his telescope, are identical with the split or divided part

Fig. 15.



of the ring as seen by Sir John Herschel, and he further observes, that with each increase of optical power, the structure of this object becomes more complicated and more unlike anything which could be supposed to result from any form of dynamical law of which we find a counter-part in our own system.

Before dismissing this very interesting subject of telescopic tests, we shall indicate one other, scarcely less remarkable. In fig. 17, is shown a small annular nebula, of a slightly oval form, observed and drawn by Sir John Herschel; the dark space in the centre of the ring he described to be filled with nebulous light, and that the edges were not sharply cut off, but were ill-defined, and exhibited a curdled and confused appearance, like that of a star seen with a telescope out of focus.

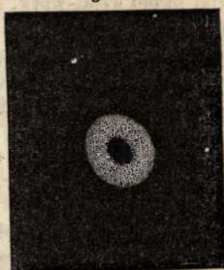
The same object as seen with the more powerful telescope of Lord Rosse, is shown in fig. 18.

It is evident from this that very little more increase of optical

Fig. 16.

power would resolve this extraordinary object into an annular mass of stars.

Fig. 17.

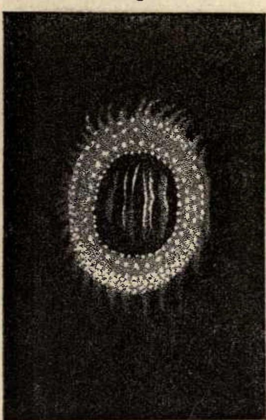


21. Seeing then that the stupendous works of creation, existing in regions of space at measureless distances from the earth, have supplied such an unlimited variety of telescopic test-objects, it was natural to seek in other parts of creation where the more minute workmanship of nature has play for a corresponding series of microscopic test-objects. At the moment when that great and rapid improvement in microscopes was commencing, which was so powerfully promoted by the scientific and practical skill of the late Dr. Goring and Mr. Andrew Pritchard, it was found that various minute parts of the structure of certain species of insects could be rendered distinctly visible only by instruments possessing certain degrees of optical efficiency.

Dr. Goring, accordingly, selected a certain number of these objects, which he arranged in a graduated series, according to the microscopic powers required to render distinctly visible the details of their structure. These objects consisted chiefly of minute scales, detached from the bodies and wings of certain species of

insects; the striæ and dots upon which could be seen with more or less distinctness, according to the excellence of the instrument. It was to these that the name *test-objects* was first applied.

Fig. 18.



22. As the microscope has been improved in its power from year to year, these test-objects have increased in number; new details of structure being developed by every increase of power and efficiency in the instrument. A certain list of such objects has been agreed upon by general consent, and prepared for sale by the makers, consisting of hairs, scales, and feathers of insects; as, however, it is not my present purpose to enter into any explanation on the subject of microscopic tests, except so far as may be necessary to elucidate one of the uses of microscopic engraving, it will be sufficient here to give a few examples of these test-objects.

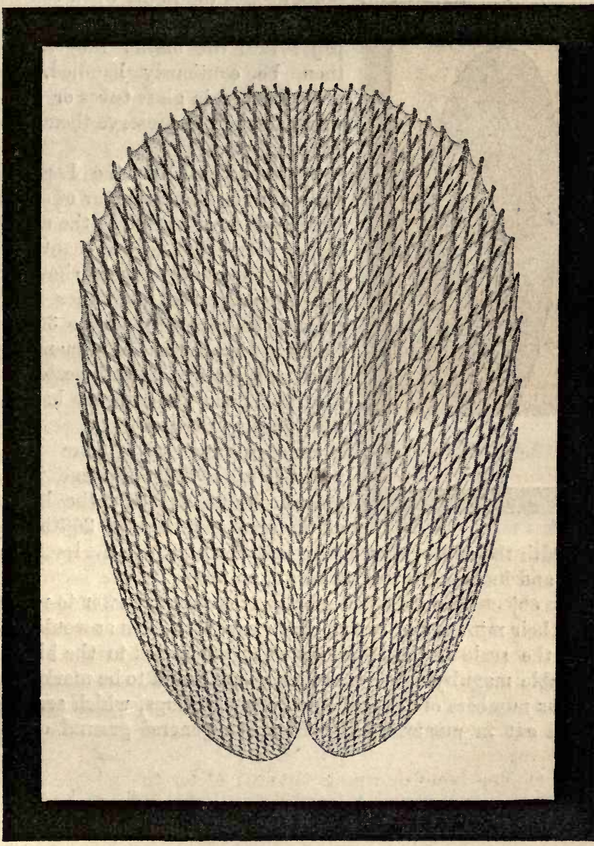
23. There is a little insect, vulgarly called the *silver-fish*, or the *silver-lady*, of which the proper entomological name is the Lepisma-Saccharina; it is usually found in damp and mouldy cupboards, and in old wood-work, such as window-frames. The silvery lustre from which it takes its vulgar name, proceeds from a coating of scale-armour, with which its entire body is invested. These scales, when detached from the insect, and examined with a microscope, present a beautiful striated appearance; their magnitude varies; one, whose length is the 114th, and width the 170th part of an inch, is shown in fig. 19, as it appears in a good microscope, magnified 400 times in its linear, and therefore 160000 times in its superficial dimensions.

The scale, as here shown, is divided along the middle of its breadth, by a sort of geometrical axis, on either side of which the structure is perfectly similar. A regular series of striated lines diverge from this axis, at an angle of about 45°, intersected by another series, very nearly parallel to the axis.

The divergent striæ are very slightly curved; the concavity being presented downwards, and the longitudiual ones ought to appear with a microscope to stand out in bold relief, like the ribs seen on certain shells; they are more closely arranged as they approach the lower part of the scale, and become more prominent as they are more separated in proceeding upwards.

Although the Lepisma is usually ranked among the test-objects it must be observed that it is one of the lowest order, an instrument

Fig. 19.

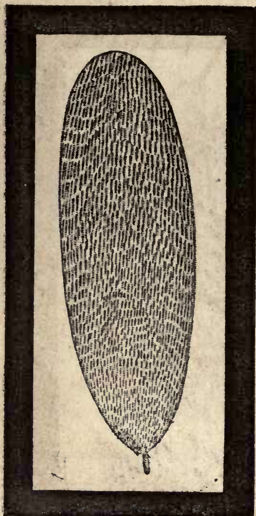


of the most moderate efficiency never failing to render the striæ tolerably distinct.

24. The Podura, or common Spring-tail, is a little insect, generally found in great numbers in damp cellars, where they may be seen, running and skipping about upon the walls. Mr. Pritchard recommends the following method of collecting them: Sprinkle a little oat-meal or flour upon a piece of blackened paper, and place

it near their haunts; the meal serving the purpose of a bait, they will soon collect upon it; the paper may then be removed, and being placed in a basin, should be brought into the light, when the insects will immediately jump from the paper into the basin: they should then be cautiously handled, and placed either in glass tubes or boxes with camphor, to preserve them from other insects.

Fig. 20.



These insects, like the Lepisma, are covered with an armour of scales, which, when submitted to the microscope, are found to be beautifully striated; one of them is shown in fig. 20, magnified 550 times in its linear, and, consequently, 302500 times in its superficial dimensions. The real length of this scale was the 260th, and its extreme breadth the 700th, part of an inch.

Smaller, and still more finely marked, scales of the same insect are shown in fig. 21; the length of the greater being the 250th, and its breadth the 500th, of an inch; and the length of the lesser the 700th, and its breadth the 1375th, of an inch.

These objects require much greater microscopic power to render visible their minute and beautiful tracery, than such as would suffice for the scale of the Lepisma, when submitted to the highest practicable magnifying powers; they are found to be marked by countless numbers of delicate cuneiform markings, which are seen to stand out in manifest relief from the general ground of the scale.

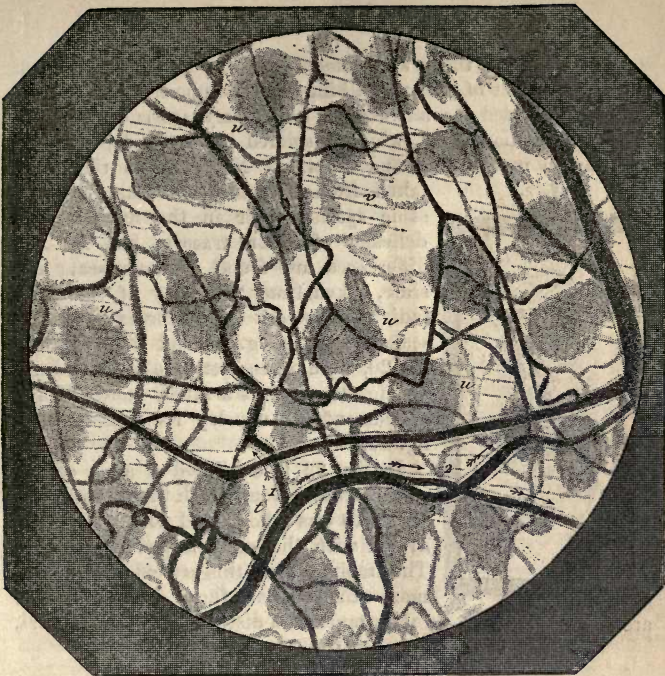


Fig. 39.—VIEW OF THE BLOOD-VESSELS AND OTHER PARTS IN A PORTION OF THE UPPER SURFACE OF THE TONGUE OF A FROG, THE REAL MAGNITUDE OF THE SURFACE DELINEATED BEING A CIRCLE THE 120TH OF AN INCH IN DIAMETER. DAGUERREOTYPED BY MESSRS. DONNÉ AND FOUCAULT.

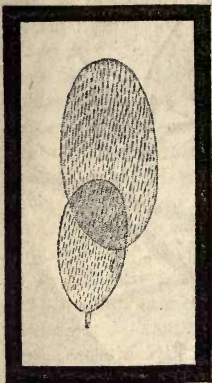
MICROSCOPIC DRAWING & ENGRAVING.

CHAPTER II.

25. Natural tests not invariable.—26. Natural tests imperfect standards. —27. Nobert's test-plates.—28. The degree of closeness of their lines. —29. Their use.—30. Apparent error respecting them.—31. Froment's microscopic engraving.—32. Method of executing it.—33. Various methods of microscopic drawing.—34. Drawings by squares. —35. Dr. Goring's drawings.—36. Structure and metamorphosis of insects.—37. The day-fly.—38. The larva of this insect.—39. Its organs of respiration.—40. Its general structure.—41. Its mobility.—42. State of chrysalis.—43. The perfect insect.—44. The production and deposition of its eggs, and its death.—45. Death may be delayed by postponing the laying of the eggs.—46. They take no food.—47. Their countless numbers; their bodies used as manure.

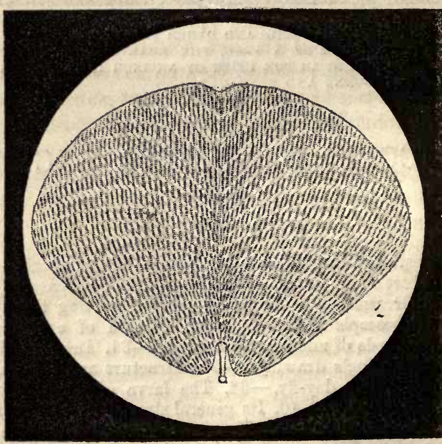
25. ALTHOUGH these, and numerous other objects selected from the minute parts of the animal kingdom, have been proposed, and generally adopted, as microscopic tests; they are subject to the obvious objection, that, when considered as standards, they are wanting in permanence and identity. Not only do the scales taken from different individuals of the same species differ in the fineness and delicacy of their tracery, but striking differences are found between scale and scale, taken from the body of the same individual insect. Thus, for example, the scales shown in fig. 21, and that shown in fig. 20, were taken from the same Podura, yet fig. 21 requires a much more efficient instrument to develop its tracery than fig. 20.

Fig. 21.



In fig. 22 is exhibited a scale of the same Lepisma from which that represented in fig. 19 was taken; and which has been drawn with the same magnifying power. The tracings upon this are evidently much more minute than those on fig. 19, and are consequently shown with much less distinctness. It appears,

Fig. 22.



therefore, that these two scales, taken from the same individual insect constitute different microscopic standards.

26. The erroneous estimates of the relative efficiency and power of different microscopic instruments which would result from the use of such test-objects, are obvious. A microscopist in London, observing the tracery of the scale of a Podura, and another at New York observing another scale of the same insect, the former failing to see its striæ, which would be visible to the latter, it could not at all be safely inferred, that the instrument of the one was inferior in efficiency and power to that of the other; and it might even happen, that the instrument which failed to show the striæ in London, was, nevertheless, superior to that which rendered them distinctly visible in New York. The result of such a comparison would entirely depend upon the structure of the two scales adopted as tests, which might differ within very wide limits.

Independently of this uncertainty attending the application of such tests, there is another not less serious objection to them; they hold out a temptation to microscope makers who supply them with the instruments they sell, to select such only as are most easily rendered visible; and although it be true that this is an expedient to which the most respectable class of makers would not resort, it is nevertheless true that the inferior makers do so, and thereby do injustice to those who are above such practices.

Natural objects, therefore, do not supply such permanent and unalterable tests for the microscope as the double stars, stellar clusters, and nebulæ do for the telescope; and this circumstance has directed the attention of the higher class of artists, to the production of artificial test-objects which shall have determinate and certain qualities, and which, like manufactured articles, may be reproduced with such absolute identity as to supply standards of comparison that can be applied in different places, and at different times, to different instruments, so as to give results which will admit of comparison.

27. The production of micrometer scales, by Mr. Froment, the divisions of which are separated by intervals so small as the 25000th of an inch, has been already mentioned.

Now the lines marking such divisions being in closer proximity than those of the tracings upon certain test-objects, it will be evident that artificial test-objects might be made by means similar to those by which such scales have been executed, and there can be little doubt that the great artistic skill which has succeeded in producing traces, separated by the small interval above named, could be pushed further, so as to produce striated surfaces, which would serve all the purposes of test-objects.

Mr. Nobert, of Griefswall, in Prussia, has taken up this problem of test-objects, and, without attempting, as it would appear, to engrave micrometric scales, which would require intervals of some

exact aliquot part of a standard unit of length, has, nevertheless, produced bands engraved by a diamond point on slips of glass, consisting of a greater or less number of parallel lines, separated by intervals of surprising minuteness.

Some remarkable specimens of the production of this eminent artist were presented at the Great Exhibition in Hyde Park, in 1851. They consisted of ten bands, each composed of a certain number of parallel lines; those in each band being closer together than those in the preceding one. In the following table, we have given in the second column the number of lines which would fill the breadth of an inch in each succeeding band in one of these specimens.

I.	11265
II.	13142
III.	15332
IV.	17873
V.	20853
VI.	24309
VII.	28433
VIII.	33153
IX.	38613
X.	49910

Thus it appears that, in this specimen, the closeness of the ruled bands varied from 11000 to 50000 to the inch.

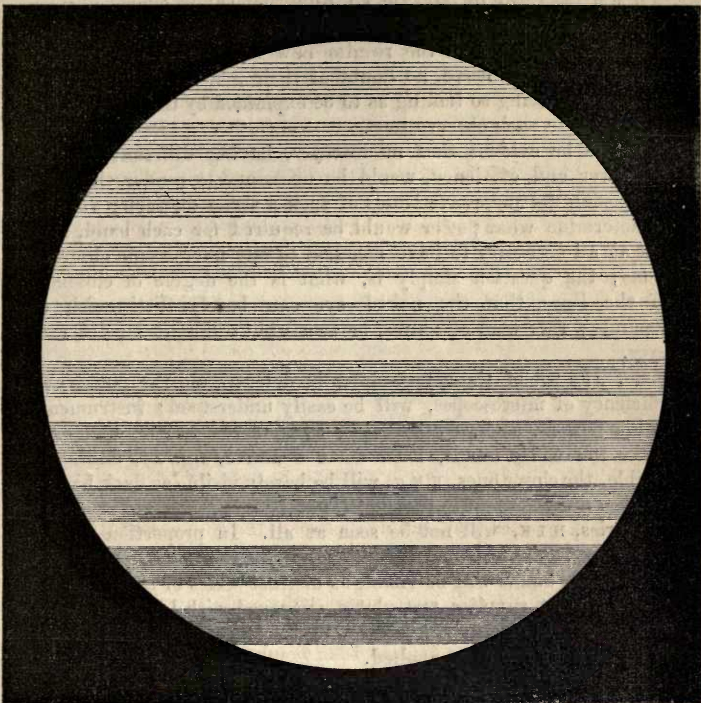
These bands are ruled on glass in parallel directions, being separated band from band, by comparatively wide intervals, so that, if sufficiently magnified, they present such an appearance as is shown in fig. 24. The highest band being that in which the lines are most separated, and the lowest that in which they are closest.

It is very difficult to convey a correct idea of the real appearance of this system of engraved bands before it is magnified; let us suppose, however, that fig. 23 represents the real magnitude of the slip of glass upon which the engraving is made, and that the white circle in the centre is the part of the glass across which the series of ten bands, shown in a magnified form in fig. 24, are drawn. The entire space occupied by all the ten bands will then be less in width than the black line which is drawn across the white circle in fig. 23. It must not be imagined that the white circle in fig. 23 represents that shown in fig. 24, the latter corresponds with a minute circular space in the centre of fig. 23, not much greater in diameter than the breadth of the black line.

Fig. 23.

28. Various other test-plates have been engraved, and put in circulation by Mr. Nobert; I subjoin the analysis of one consisting

Fig. 24.



of 15 bands, which has been examined and calculated by Mr. De La Rue.

Series.	Number of lines.	Distance in relation to the English inch.	Number of lines in an English inch.
1	7	0·00008880	11261
2	8	0·00007548	13248
3	9	0·00006482	15427
4	10	0·00005506	18162
5	11	0·00004884	20475
6	13	0·00004262	23463
7	15	0·00003552	28153
8	17	0·00003108	32175
9	19	0·00002664	37537
10	21	0·00002442	40950
11	23	0·00002220	45045
12	24	0·00002113	47326
13	26	0·00001998	50050
14	27	0·00001891	52882
15	29	0·00001776	56306

I am informed by Mr. De La Rue, that bands engraved upon other plates, were observed and computed by himself, Mr. Lister, and Mr. Nobert, and the results now before me, are in such accordance as to leave no doubt of their general accuracy, the discrepancy being so trifling as to be explained by the small errors inevitable in such observations.

It will be evident that microscopes, having different degrees of power and efficiency, would be necessary to render the lines composing the successive bands of such a series distinctly visible; to determine what power would be required for each band, it is not at all necessary to have recourse to any microscopic observations; the question simply is, what is the degree of closeness of the lines, that the naked eye can barely distinguish as separate; this will, of course, be somewhat different for different eyes.

29. The use of these test-plates in determining the power and efficiency of microscopes, will be easily understood; instruments of low powers, such, for example, as from 100 to 200, will only make the wider bands, such as A B and C, fig. 24, distinctly visible, the closer ones, E F G, will be barely visible as dark bands, but the lines composing them will not be seen, and the closest of the series, H I K, will not be seen at all. In proportion as the power and efficiency of the microscope is increased, more and more of the bands will be visible as distinct series of lines.

Mr. Nobert supplies test-plates, engraved with bands of different degrees of closeness, according to the power of the instruments to which they are to be applied.

30. In the Report of the Juries of the Great Exhibition of 1851, page 268, it is stated, that to see the bands of a test-plate of 10 bands, such as that described above, a linear magnifying power of 100 is necessary for the wider bands, such as I and II, but that to distinguish those of the closest band, such as X, a magnifying power of 2000 is necessary.

I think it is apparent that this statement is erroneous, being evidently incompatible with the relative closeness of the lines of the several bands. Thus, for example, while there are 11265 lines of the first band to an inch, there are 49910 lines of the tenth band to an inch. Those of the latter are, therefore, only 4½ times closer than those of the former; and it is evident, that if these bands be viewed with two microscopes, one having a magnifying power 4½ times greater than that of the other, with proportional defining and illuminating powers, the lines composing them will appear equally separated; and since it is admitted in the report, that a power of 100 will render the lines of the first band visible, as it evidently will do, it will follow that

a power of 450 will render the lines of the tenth band equally visible; indeed, it is not necessary at all to have recourse to the microscope to ascertain the effect which a given magnifying power ought to produce upon a band of a given degree of closeness, since it is evident that the effect must be merely to make the lines composing the bands more widely separated than they are in the exact proportion of the magnifying power. Thus, if the lines composing a band, separated by intervals of the 10000th part of an inch, be viewed with the magnifying power of 100, they will appear as those of a band separated by intervals of the 100th of an inch; and if it be viewed with a magnifying power of 1000, it will appear as if the lines were separated by the 10th of an inch, and so on.

Now, let us apply this obvious principle to the case given in the report of the Juries; a magnifying power of 100 directed upon the first band, would make the lines appear as if they were separated by intervals of the 112th part of an inch; those of the second band would appear separated by intervals of the 131st part of an inch, and those of the third by the 153rd part of an inch. Now, all these would, as admitted in the report, be distinctly seen as separate lines, by eyes of average power. But let us see what effect a magnifying power of 2000 would produce upon the closest of the bands.

Since it would render the apparent intervals between line and line 2000 times greater than they are, those between the lines of the tenth band, would be the 25th; those of the ninth, the 19th; and those of the eighth, the 17th part of an inch.

Although it must be quite evident that such intervals are much greater than is necessary to enable any eye whatever that can see at all, to perceive the lines distinctly separated, the reader will be enabled better to appreciate the point by referring to the numbers which we have placed on the right of fig. 24, which express severally the number of lines to an inch in each of the bands composing that figure; thus, the lines of the bands B and C are separated by intervals of the 48th part of an inch; and it follows, therefore, that a magnifying power directed upon the band X of the test-plate, mentioned in the report of the Juries, would, if viewed by a power of 2000, show the lines separated by intervals twice as great, or equal to those of every other line in the bands B and C, fig. 24.

For these reasons, it appears to me that a mistake has been committed in the report of the Juries in this point, and I have thought it the more desirable to call attention to it, inasmuch as the statement has been reproduced in several recent works upon the microscope.

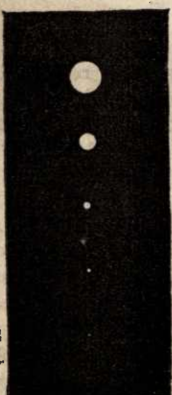
It is easy to show what would be the degree of closeness of the

lines composing a band, which a power of 2000 would barely render visible to average eyes. Assuming that such eyes could see distinctly without microscopic aid the lines of a band consisting of 150 to an inch, it is evident that a power of 2000 would render equally visible those of a band, the lines of which would be 300000 to an inch. I am not aware that Mr. Nobert, or any other artist, has ever produced such lines, and consequently doubt the existence of any such artificial test for a power of 2000.

31. I now come to notice a sort of microscopic engraving, which, though it is at once the most curious and difficult, has not, so far as I am informed, had as yet any directly useful application. Regarded, however, as an example of mechanical ingenuity and skill, and as an artistic *tour de force* of the highest order, it is full of interest.

However much we may admire the production of the micrometric scales and microscopic test-plates described above, there is nothing in them to excite surprise, save the precision which is combined with such extreme minuteness. To draw a series of parallel lines of regulated length and uniform intervals, is a problem, to the solution of which it is easy to conceive that finely constructed mechanism can be adapted; but when it is proposed to delineate objects and characters, in which no such regularity prevails, and, in tracing which, the point of the graving tool must pursue a course determined by conditions, which obviously cannot be represented by any kind of mechanism, and to accomplish which it must be guided, directly or indirectly, by the hand, a problem of quite another, and far more difficult order, is presented: such, however, is the curious and complicated problem for which Mr. Froment, already named, has found a solution.

Fig. 25.



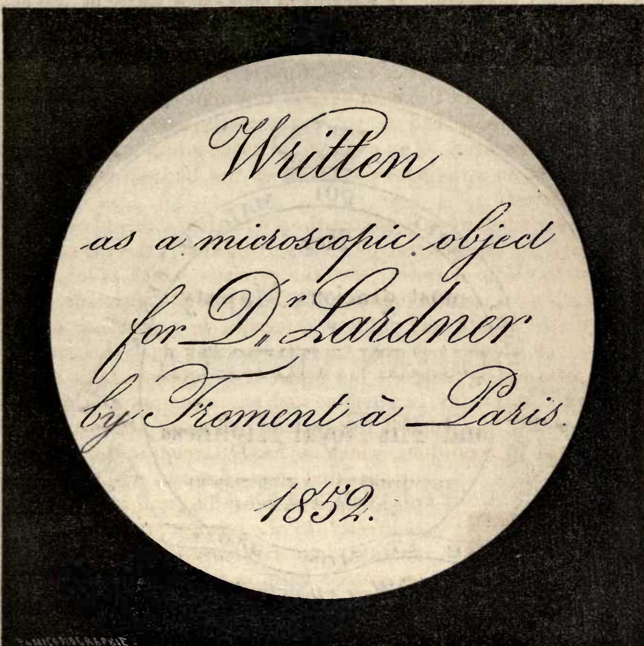
This eminent artist has succeeded in producing manuscripts and drawings, engraved upon glass, on a scale of minuteness in no degree less surprising, though far more difficult of execution than the test-plates of Mr. Nobert.

To enable the reader more easily to appreciate these wonderful productions, we have given in fig. 25 the forms and magnitudes of five small circular spaces, A, B, C, D, E, the diameters of which are severally the 6th, 12th, 30th, 70th, and 160th of an inch.

Mr. Froment wrote for me, in less than five minutes, within a

circle of glass, the 40th of an inch in diameter, less, therefore, by one third than the small white spot C, fig. 25 ; the sentence which, when magnified in its linear, 120, and in its superficial dimensions, 14400 times, presented the appearance shown in fig. 26.

Fig. 26.



On the occasion of the Great Exhibition in 1851, the characters and figures shown in fig. 27 were engraved by Mr. Froment, within a circular space equal to that shown at C in fig. 25.

32. As the method by which these marvellous effects are produced is not yet patented or made public, we are not at liberty to explain its details; but it may be stated generally to consist of a mechanism by which the point of the graver or style is guided by a system of levers, which are capable of imparting to it three motions in right lines which are reciprocally perpendicular, two of them being parallel, and the third at right angles to the surface on which the characters or design are written or engraved. The combination of the motions in the direction of the axis parallel to the surface on which the characters are engraved or written,

determines the form of the characters, and the motion in the direction of the axis at right angles to that surface determines the depth of the incision, if it be engraving, or the thickness of the stroke, if it be writing.

33. Having thus explained the principal results of the art of microscopic engraving, it remains to offer some notice of the not

Fig. 27.

APPEARANCE AS SEEN IN THE FIELD OF THE MICROSCOPE, THE OUTER CIRCLE BEING ONLY THE 30TH OF AN INCH IN DIAMETER.

less interesting methods of delineating microscopic objects, or transferring to paper, metals, or wood fac-similes of the appearances presented in the microscope. The methods of accomplishing this have varied with the varying resources presented to art, by the progress of the sciences.

34. The first attempts at delineation of this kind were made by dividing the field of the microscope into a system of squares, by

means of micrometer threads or wires extended transversely to each other across the field of view, as shown in fig. 4. By this means, the field of view was, as it were, mapped out in squares, like lines of latitude and longitude, upon which the magnified images of the objects to be delineated were seen projected. The draftsman having previously prepared on paper a corresponding system of lines, transversely intersecting each other at distances, one from another, determined by the scale of the intended drawing, he proceeded to trace the outlines of the objects, guided by the correspondence between the system of squares upon his paper, and the system of squares seen in the microscope. The outlines being then obtained, which could always be most conveniently done with a low magnifying power, which would include at once within the field the entire object, or objects, to be drawn, the minute details of form and structure, were filled up within the outlines by viewing the parts of the object successively with much higher powers.

Neither this method, nor any other, depending on mere mechanical experience, would admit of being applied to the delineation of living objects, which are liable constantly to shift their positions and change their attitudes. To delineate these, the microscopist must also be an artist, and one of rather a high order; happily, the combination of the two qualities was not unfrequently found, and many beautiful representations, on a magnified scale, of the minuter members of the creation, have been supplied by the researches and talents of microscopic observers.

35. We shall select from these one or two admirable examples supplied by the late Dr. Goring; and it will not be unacceptable to the reader, if we accompany them with a brief account of the objects they represent.

36. For those who have not devoted attention to the history of the insect world, it may be well here to premise, that these little creatures are generally produced from eggs, and that, unlike all other members of the animal kingdom, they pass during their life through three stages of existence, in which their forms, habits, nourishment, and dwellings, differ one from another, for the same individual insect, as widely as do those of a crocodile and a peacock.

37. There is a certain little insect of the class of flies, called a day-fly, because the duration of its life, from the moment it attains the third and perfect stage of its existence never exceeds a day.

This insect deposits its eggs in water, well knowing, as it would seem, that its young, when hatched, are destined to be aquatic animals, although it is itself one of the gayest animals of the air.

In due time, generally towards the decline of summer, the young, breaking the shell, issues from the egg in the form proper to the first of the three stages of its existence, in which it is called a *larva*; its length, when full grown, in this state, is about half an inch, and it is represented in its proper magnitude in fig. 28. It is represented magnified in its linear dimensions $6\frac{1}{2}$ times; and, therefore, in its superficial dimensions, 42 times, in fig. 29.*

Fig. 28.

38. As the larva increases in size, the serpentine vessels attached to its sides become more apparent, and the tail assumes that rich feathered appearance which, in conjunction with the paddles projecting from its sides, constitute one of its most beautiful features.

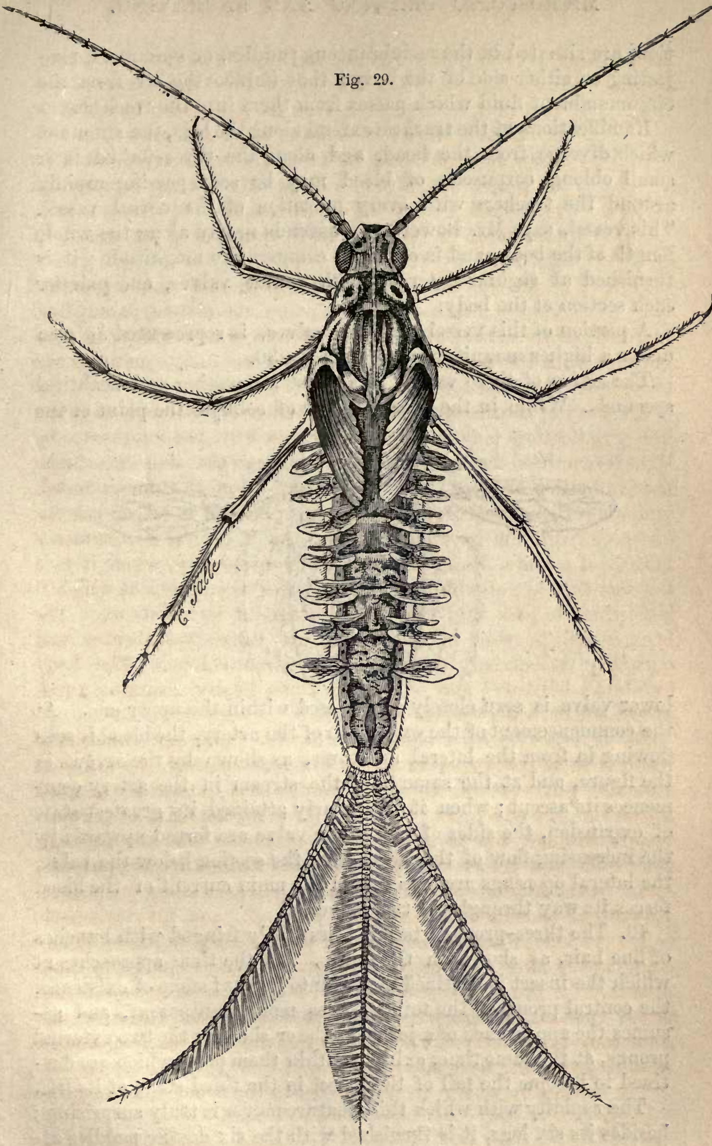
The body of the insect when young, being very pellucid, its internal organisation may be very clearly seen with the microscope by light transmitted through it. The peristaltic motion of the intestines; the circulation of blood, and the pulsations of the dorsal vessel, which in these creatures supplies the place of a heart, can be observed with the greatest facility. As it grows, it assumes a variety of colours, losing much of its transparency, when it is a few months old; at which time, the period approaches at which it is destined to pass into the second stage of its existence. The eyes, as will be seen in the figure, are large, protuberant, and curiously reticulated; they are of a citron colour. The body exhibits a beautiful play of various tints, finally assuming a rich brown colour, with various shadings.

39. It must be here observed, that the important function of respiration is performed in a very different manner, by different animals; the breathing apparatus being always admirably adapted to the element which they inhabit. The higher class of animals respire through the mouth and nose. Fishes take air through their gills, and insects through orifices provided for the purpose, either in the hinder extremity of their bodies, or along their sides. From these openings, the air passes through, and inflates vessels called tracheæ, which extend along their sides; in these it encounters the blood, on which it produces effects similar to those produced in the superior animals. These vessels appear in the figure running along each side of the body, and throwing out numerous ramifications which traverse the several leaf-shaped paddles projecting from the body.

The orifices by which air is supplied to the tracheæ for respira-

* This figure and the succeeding ones, drawn by Dr. Goring, have been copied with the permission of Mr. Pritchard from the microscopic illustrations.

Fig. 29.



MAGNIFIED VIEW OF THE LARVA OF THE DAY-FLY. DRAWN BY DR. GORING.

tion, are situated in the membraneous paddles, or swimmers, projecting on either side of the body; they imbibe the air from the circumambient fluid which passes from them into the tracheæ.

Ramifications of the tracheæ extend along the legs, the antennæ, which diverge from the head, and along the three-forked tail; small oblong corpuscles of blood may be seen passing rapidly around the tracheæ with every pulsation of the dorsal vessel. This vessel, says Mr. Bowerbank, extends nearly along the whole length of the body, and is of great comparative magnitude; it is furnished at regular intervals with double valves, one pair for each section of the body.

A portion of this vessel, with its valves, is represented as seen under a higher magnifying power in fig. 30.

The action of these valves is a most interesting and beautiful spectacle. While in the greatest state of collapse the point of the

Fig. 30.

lower valve is seen closely compressed within the upper one. At the commencement of the expansion of the artery, the blood is seen flowing in from the lateral apertures, as shown by the arrows in the figure, and at the same time the stream in the artery commences its ascent; when it has nearly attained its greatest state of expansion, the sides of the lower valve are forced upwards by the increasing flow of the blood from the section below the valve, the lateral openings are closed, and the main current of the blood forces its way through the two valves.

40. The three-pronged tail is beautifully fringed with bunches of fine hair, as shown in the figure. As the time approaches at which the insect is destined to pass into its next stage of existence, the central prong of the tail becomes more transparent, and assumes the appearance of a jointed tube or sheath; the two external prongs, at the same time, exhibit within them parts which are destined to become the tail of the insect in the third stage of its life.

The rapidity with which this creature moves is truly surprising; besides its six legs, it is furnished with the six double paddles attached diagonally to the serpentine vessels on each side of its

body, and with its tail, all of which it employs for rowing, balancing, and guiding itself in the water, the tail playing the part of the rudder.

41. Such is the mobility of these members, that even when the creature is in repose, all the paddles are in rapid motion; the steering prong of the tail alone being at rest.

Independent of its faculty of locomotion by means of its legs, paddles, and tail, it possesses a power of leaping and springing in the water, by bending its body backwards, and then suddenly straightening it; by this movement it raises itself to the surface with great celerity.

42. During the second stage of the life of this insect, called the state of chrysalis, it retains the faculty of swimming; its motions are altogether subservient to its will, and it leaps with great alacrity. As the epoch, however, approaches at which it is to pass into the third and most perfect state, in which it receives the name of day-fly, some parts of it assume a metallic lustre, just as if the thin casing in which it is wrapped like a mummy, were partly filled with mercury; this casing is so thin and translucent, that every part of the body of the perfect insect, which is soon about to emerge from it, is plainly enough visible through it. The metallic appearance, just mentioned, is supposed to arise from the evolution of a small quantity of gas from the body of the insect in the change which it is undergoing; this gas, by insinuating itself between the case of the chrysalis and the body of the insect, helps to detach the former from the latter, and thus facilitates the natural process by which the insect emerges from its prison. The envelope of the chrysalis is adapted to the form and members of the insect, just as a glove is to the hand, so that after the insect has escaped from it, this envelope will exhibit with great precision its shape and proportions.

43. When the creature has divested itself of its envelope, it remains apparently inert for a few minutes on some neighbouring

Fig. 31.

plant, where it carefully cleanses its wings, and divests them of the last pellicle of the sheath in which they had been inserted; it then assumes the beautiful form, and exercises the functions

which appertain to it in the perfect state, and becomes the day-fly shown in fig. 31.

44. It now rises upon its wings into its new element, the air, where it joins tens of thousands of its fellows, who have almost simultaneously undergone a similar transformation. In the fine afternoons of summer and autumn, swarms of these creatures may be seen hovering in the air, all of them having emerged the same day from the state of chrysalis. Each female in these flights seeks its mate; which having chosen, they retire together to the leaves of some neighbouring plants. Immediately after their conjugal union, their proceedings are such as would be prompted by the tenderest parental solicitude for their future offspring, which, however, they are never destined to behold. Conscious, apparently, that their young must inhabit a very different element from that in which their short existence passes, they fly off in quest of water, in which, when found, the provident mother deposits her eggs, collected in a little packet in which they can float; the parents then abandon them to the warmth of the atmosphere, by which they are subsequently hatched, and having thus performed the last and most important duty of their life, that of increasing and multiplying their species, drop dead, the whole period of the existence of this gay insect being limited to a few hours of a summer afternoon.

45. So imperious is the will of nature in enforcing her laws, that if by artificial interference, the insect after emerging from the envelope of the chrysalis be prevented from joining its fellows and kept in solitude, its life will be prolonged far beyond its natural term, as if it lived only for the performance of the duty prescribed to it by its Maker. Dr. Goring ascertained this fact by catching a day-fly just emerged from the chrysalis, which he imprisoned for several days, during which it continued to live; he observed that in such cases the insect did not seem at all enfeebled, even when thus confined for a week, so that upon being liberated it flew briskly away, found its mate, produced and provided for its eggs, and immediately died.

46. It is remarkable that these little creatures, during their ephemeral existence, take no food; the only function they exercise being that of propagation.

47. It appears, that in some localities, these flies prevail in such countless numbers that their bodies are found after death covering the ground to a considerable depth, and they are collected in cart loads by the agriculturists, who use them for the purpose of manure.

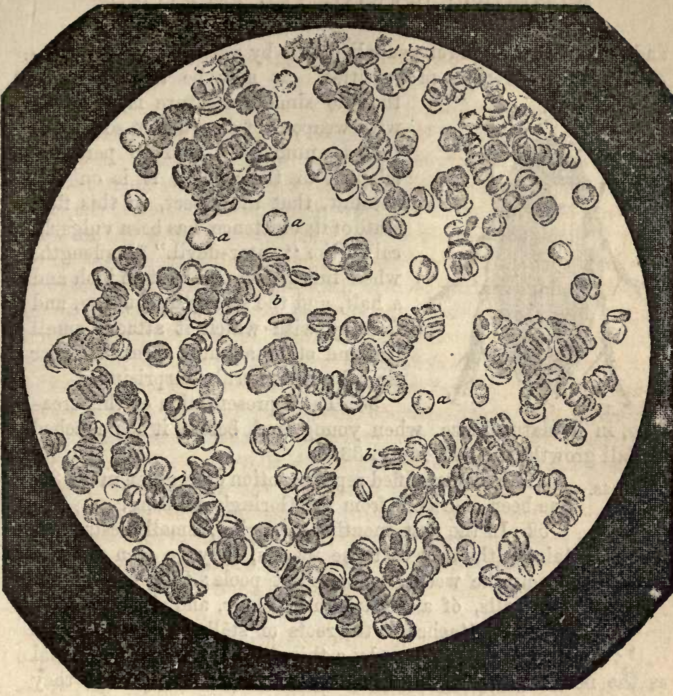


Fig. 38.—VIEW OF A THIN DISC OF HUMAN BLOOD, PRESSED BETWEEN TWO PLATES OF GLASS, THE REAL DIAMETER OF THE PART SHOWN BEING THE 120TH OF AN INCH, DAGUERREOTYPED BY MESSRS. DONNÉ AND FOUCAULT.

MICROSCOPIC DRAWING & ENGRAVING.

CHAPTER III.

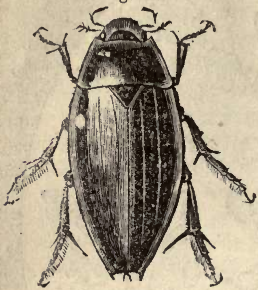
48. The beetle.—49. Its larva.—50. Drawing of it in its natural size.—51. Dr. Goring's magnified drawing.—52. Production of the beetle from the egg.—53. The young larva.—54. Its voracity and manner of seizing its prey.—55. Description of its organs.—56. Its chrysalis.—57. Water-beetle.—58. Gnat.—59. Dr. Goring's method of drawing.—60. Drawing by the camera-lucida.—61. Section of the human skin; sweating-gland and duct.—62. The itch insect.—63. Method of obtaining it.

48. ANOTHER of the tribe of insects, of whose larva Dr. Goring has left a beautiful drawing, is the beetle, shown in fig. 32.

49. The larva of this insect, like the former, is an inhabitant of the water. It is remarkable for its ferocious and savage disposition,

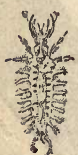
and for the various organs supplied to it by nature for the gratification of its ravenous propensities. It may be truly affirmed that no similar creature is provided with weapons of destruction so powerful, so numerous, and so perfectly adapted to their end ; it is on this account, that the insect, in this first state of its existence, has been vulgarly called the "water-devil." Its length, when full grown, is about an inch and a half, and the strength, courage, and ferocity with which it attacks small fish and other aquatic animals larger than itself, are truly surprising.

Fig. 32.



50. The representation of this creature, in its natural size, when young, and before it has reached its full growth, is given in fig. 33.

Fig. 33.



51. The magnified representation of it given in fig. 34, has been engraved from Dr. Goring's drawing.

52. In the first months of Spring, small nests containing the eggs of these insects, may be seen floating among the weeds, in stagnant pools; they are formed like balls, of a dusky-white colour, and silky texture; they are attached to the roots or stalks of weeds at the bottom of the water by a thin stem of the same material as the nest, but stronger and more dense. Thus placed, they remain during the winter preserved from the effects of cold, even when the surface of the water is frozen over ; since by a natural thermal law the temperature increases in going downwards.*

Early in spring, the stem or thread by which they are attached to the weeds, is broken by the winds, and the nest being detached and lighter, bulk for bulk, than the water, rises by its buoyancy to the surface, where being exposed to the warmth of the sun as the season advances, the eggs are hatched. The larva, however, after breaking the shell, is still confined in the bag-shaped nest; it accomplishes its liberation by gnawing a hole in it, from which escaping, it dives immediately to the bottom, eagerly devouring all the small aquatic insects that fall in its way. If, however, it should happen that there is a short supply of this food, the voracity of these creatures is such, that they fall upon and devour each other.

53. When the larva is very young, measuring not above a quarter of an inch in length, it is sufficiently translucent to enable an observer to see its internal structure with the microscope, by light

* See Tract on "Terrestrial Heat," also Handbook of Natural Philosophy, "Heat."

THE WATER DEVIL.

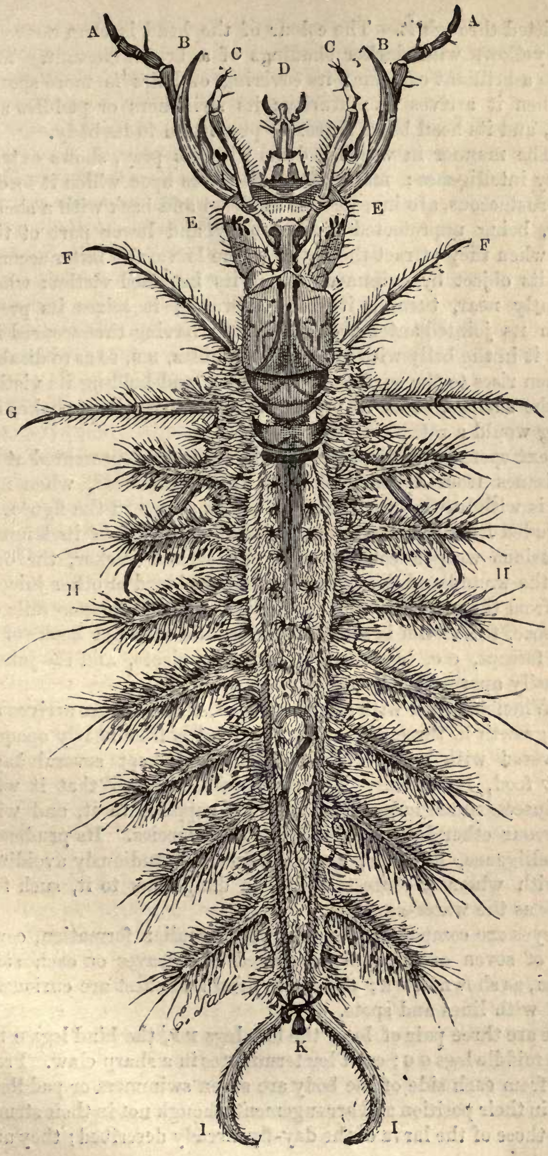


Fig. 34.—MAGNIFIED VIEW OF THE WATER-DEVIL OR LARVA OF THE BEETLE. DRAWN BY DR. GORING.

transmitted through it. The colour of the head is then a strong Indian yellow, with darker shadings of a bright chesnut. The eyes are a brilliant carmine; its covering of hairs is more sparse than when it arrives at maturity; its swimmers or paddles are shorter, and its head bears a greater proportion to its body.

54. The manner in which it deals with its prey, shows extraordinary intelligence; many of the creatures upon which it feeds, being crustaceous, are invested on the head and back with a shell-armour, being unprotected on the belly and lower part of the body; when they attract the notice of the larva, the latter accomplishes its object by swimming under its intended victim; when sufficiently near, turning its head upwards, it seizes its prey, between its jointed antennæ, A A, fig. 34; having thus secured it, it stabs it in the belly with its sharp mandibles, B B, so as to disable it, it then rises to the surface of the water, and holding its victim above the surface, so as to prevent it from struggling, shakes it, as a dog would a rat.

Its next operation is to pierce it with a weapon represented at D, which issues from a horny sheath; this instrument, when not in use, is withdrawn into the sheath. As shown in the figure, it is protruded from the sheath to about three-fourths of its length. This curious weapon consists of a piercer and sucker, the one giving the wound and the other drawing the blood or other juices. When from the nature of the part attacked, this weapon fails of its purpose, the victim is seized between the serrated hooks of a pair of forceps, C C, by which it is torn to pieces, and the juices more easily approached by the sucker, D.

55. When supplied with abundant food, this creature arrives at its full growth in three or four months, and is then nearly opaque and covered with hair. When caught and kept several days without food, its ferocity is greatly increased, so that it will attack insects much larger than itself, if supplied to it, and will even devour other individuals of its own species. Its prudence and intelligence, however, are displayed by studiously avoiding those with whom a contest would be dangerous to it, such for example as the water-scorpion.

The eyes are compound, but of a very peculiar formation, consisting of seven oval pupils, arranged like leaves on each side of a stem, as shown at E E; the entire head and chest are curiously marked with lines and spots.

There are three pair of legs, the fore legs F F, the hind legs H H, and the middle legs G G; each leg terminates in a sharp claw. Projecting from each side of the body are seven swimmers or paddles, similar in their position and arrangement, though not in their structure, to those of the larva of the day-fly already described; they are

here covered with hairs, and in the specimen from which the drawing has been made, a vast number of minute bell-shaped animalcules were attached to them, which will be recognised in the figure.

The abdomen is united to the chest or thorax a little above the first pair of swimmers, and extends to the commencement of the bifurcated tail; along the sides of the abdomen are extended the two tracheæ or air-vessels, which as already explained perform the functions of lungs; they are in this case of a light blue colour, and throw out numerous branches at various intervals in their course. These tracheæ consist of curiously formed fibres, winding round them like the twisted filaments of a rope, as may be seen in the figure. These vessels are usually distended by the air which inflates them; their diameter in a full-grown larva is about the sixteenth of an inch.

Dr. Goring states that when these membranes are submitted to examination with the microscope in the usual way, they exhibit the most beautiful specimen of line-work that it is possible to imagine. The filaments of the upper and under sides, intersecting each other at different angles, produce an effect which could not be surpassed by the finest and most beautiful engine-turning.

The orifices by which respiration is performed are at its tail, and each time that it makes an inspiration, it is obliged to ascend to the surface, above which it projects its tail, through the apertures of which it draws in air, until the entire tracheæ have been inflated; thus provided, it sinks again into its proper element, and according as the air thus inspired has changed its character by contact with the blood, and has therefore been rendered unfit for the support of life, it is expelled from the same orifices in the tail at which it entered, and may be seen rising in bubbles to the surface.

Dr. Goring observes that a comparison of the organs of respiration of this insect with those of a caterpillar, affords a beautiful example of the adaptation of their organisation to the elements in which they live. In the case of the caterpillar, every part being constantly exposed to the atmosphere, mouths or orifices for inhaling the air are arranged along both sides of the body; while in the aquatic larva, this system could not be made available without compelling the creature to elevate its entire body out of the water, each time it makes an inspiration. The necessity for this is superseded by placing the breathing-mouths in the tail.

While admitting the admirable fitness of this arrangement in the two classes of insects, it must not be forgotten, that in the case of the larva of the day-fly, also an aquatic insect, formerly mentioned, the breathing-mouths, according to Dr. Goring's

description, are placed in the membraneous paddles along its sides, and the air is imbibed from the surrounding fluid.

56. After this creature has remained for a considerable time in the state of larva, and when it appears to become conscious that the epoch of its passage into the second stage of its existence, that of chrysalis, is approaching, it issues from the water and proceeds to excavate for itself a hole in the ground, in which it undergoes the metamorphosis by which it passes into the state of a chrysalis, in which it remains for some days, after which it emerges a perfect beetle.

The female bears on each side of the hinder extremity of her body a spinning apparatus, which she uses to make the bag in which her eggs are deposited, and which has been already described.

57. Dr. Goring has also left a drawing of another species of dytiscus, called the *water-beetle.*

This insect resembles, in the manner of its propagation and its habits, that which has been above described. It is carnivorous, and of a ferocious and cruel character. If it is placed in a vessel with other aquatic insects, it soon devours them.

A magnified view of it is shown in fig. 35; the insect, in its real size, being represented in the lower figure. The drawing from which this engraving was taken, was made immediately after it had cast its first skin, a moment at which its internal organisation is more distinctly visible than at any other period of its existence, by reason of the thinness and transparency of its newly-developed vessels. Its anatomical structure is more delicate and beautiful than that of any other larva of the order of coleoptera, and, although its weapons of attack appear less formidable than those of the water-devil and some other species, the remarkable manner in which its internal functions are rendered visible more than compensate for this, when the insect is regarded merely as a microscopic object.

It is armed with a pair of curved mandibles, which move horizontally, and are long enough to cross each other when closed. They are of a fine nut colour, becoming darker towards the points, which are hard and sharp. With these the insect seizes its prey, and bringing it towards its mouth, sucks its blood after having first pierced it. This it delights to do without killing its victim, unless it is constrained to do so, by the superior strength of the latter. If it seizes the larva of the gnat, or any other tender insect, it brings different parts of its body to its mouth, devouring it piecemeal, except the skin, which it rejects. If its prey is a strong animal, protected by an external shell, it seizes it, and holds it for some time at rest, until its victim

becomes completely exhausted ; or, having wounded it in several places, it turns it upon its back and sucks its juices.

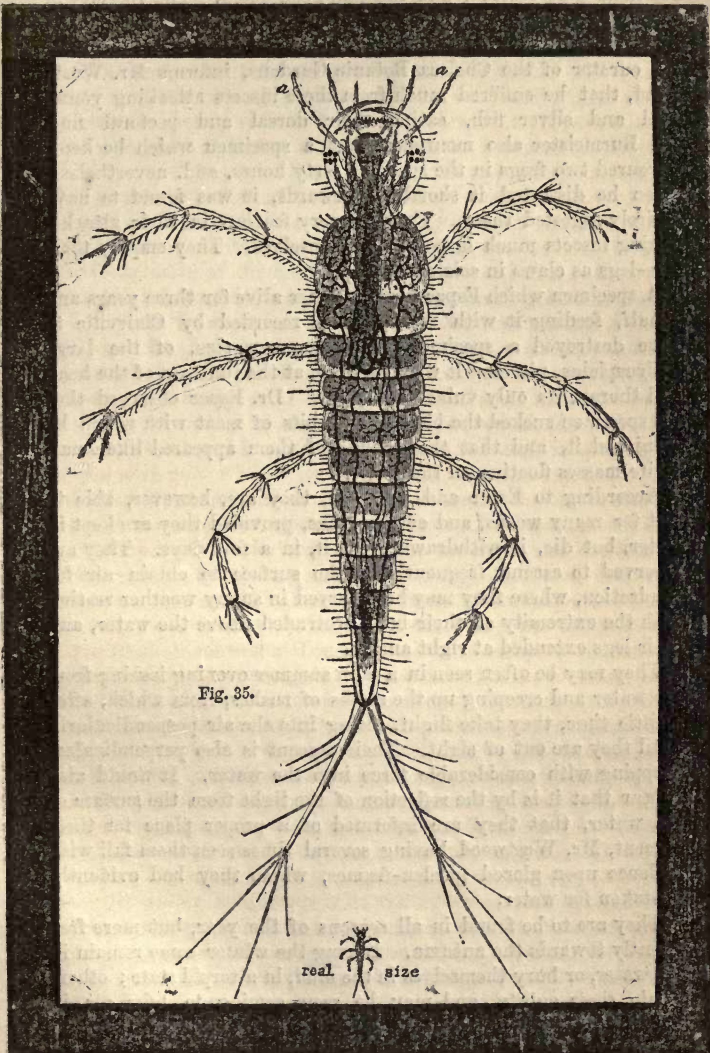


Fig. 35.

These larvæ swim with great agility, the hind legs acting together in concert like those of a frog; the antennæ being at the same time erected, and the palpi concealed. The voracity of this creature is not directed alone to aquatic insects, but proves often very destructive to young fish in fish-ponds. Mr. Anderson, the curator of the Chelsea Botanic Gardens, informs Mr. Westwood, that he suffered much from these insects attacking young gold and silver fish, eating their dorsal and pectoral fins. Dr. Burmeister also mentions, that a specimen which he kept, devoured two frogs in the space of forty hours, and, nevertheless, when he dissected it shortly afterwards, it was found to have entirely digested them. They are very fearless in their attacks, seizing insects much larger than themselves. They employ their fore-legs as claws in seizing their prey.

A specimen which Esper kept in water alive for three years and a half, feeding it with raw beef, is recorded by Clairville to have destroyed a specimen, twice its own size, of the large hydruspicius, piercing it with its jaws, at the junction of the head and thorax, its only vulnerable point. Dr. Esper observed that his specimen sucked the blood of the bits of meat with which he furnished it, and that the residue of them appeared like small white masses floating on the water.

According to Esper and Erichson, they are, however, able to fast for many weeks, and even months, provided they are kept in water, but die, if withdrawn from it, in a few days. They are observed to ascend frequently to the surface to obtain air for respiration, where they may be observed in sunny weather resting with the extremity of their body protruded above the water, and their legs extended at right angles.

They may be often seen in a calm summer evening issuing from the water and creeping up the stalks of rushes, from which, after a little time, they take flight, rising into the air perpendicularly until they are out of sight. Their descent is also perpendicular, dropping with considerable force into the water. It would also appear that it is by the reflection of the light from the surface of the water, that they are informed of a proper place for their descent, Mr. Westwood having several times seen them fall with violence upon glazed garden-frames, which they had evidently mistaken for water.

They are to be found in all seasons of the year, but more frequently towards the autumn. During the winter some remain in the water, or bury themselves in the mud, in a torpid state; others retain their agility, and may be seen coming to take air in places where the ice is broken. Mr. Westwood has seen them even swimming about in the water under the ice on which he was skating.

The female deposits her eggs about the beginning of spring, each laying consisting of from forty to fifty eggs of a long and cylindrical form, which are deposited in the water at random, the larvæ being hatched in the course of a fortnight.

The larva of the dytiscus marginalis is very active, and casts its skin, for the first time, when four or five days old. The second moulting takes place after an equal interval, and as the insect continues to grow, it casts its skin at intervals of about ten days. The hide which it throws off may often be observed floating on the water, with the mandibles, tail, and its appendages attached. These larvæ are of a dark ochre, or dirty brown colour, with the body long and subcylindric, more slender at each extremity, but especially towards the tail. The body consists of eleven segments, exclusive of the head. The first nine segments are somewhat scaly above, but fleshy beneath. The first segment is longer and narrower than the following. The sixth, seventh, and eighth, are larger than the others, which are of nearly equal size, and the two terminal joints are long and conical; the apex being slightly truncated and scaly, with the sides fringed with hairs, whereby the insect is enabled to swim along in the water, the action of these joints being the same as that of an oar used in sculling a boat.

The terminal segment of the tails is provided with a pair of long and slender pilose appendages, whereby the insect is enabled to suspend itself at the surface of the water, which, as Swammerdam says, flows from them on every side, and thus the suspension is effected. These appendages are tubular, and communicate with the air-vessels which run along the sides of the body, which is moreover furnished with a series of spiracular points, as shown in the figure. The head is large, rounded, and depressed, and united to the first segment of the body by a short neck, with five or six small elevated tubercles representing the eyes. There are two slender antennæ, shown at *a a* in the fig. 35, having a length nearly equal to the diameter of the head, inserted in front of the eyes, and composed of seven joints. The mouth is remarkably constructed, being destitute of the ordinary aperture, so that the insect may be, and, indeed, has been, described as wanting a mouth.

The mandibles, which appear in the figure projecting from the front of the head, are hollow, having a longitudinal slit near the extremity, so as to enable the creature to suck through them the juices of its prey, as a liquid is sucked through a straw or a quill, the juices thus running down the mandibles into the mouth.

The legs of the insect are long, slender, and ciliated on the inside, serving as oars when swimming quickly. The body,

generally straight, curves itself in the shape of the letter S when the creature seizes its prey. During the summer the larva is said to attain its full size in about fifteen days, when it quits the water and creeps into the neighbouring earth, where it forms with considerable skill a round cell, in which, in about five days, it changes to a pupa of a whitish colour, with two obtuse points at the extremity of the body. In about a fortnight or three weeks it issues as a perfect beetle. If, however, the change to the pupa state take place in the autumn, the creature does not pass into the form of a perfect insect until the following spring.

The beetle is at first soft and yellowish, but soon hardens and assumes a darker colour. It is not, however, until the end of eight days, that it has acquired its proper consistency.*

Dr. Goring, in describing the specimen from which the drawing was taken, says that the three first segments of the body, commencing from the neck, contain a bundle of nerves, terminating with three loops, which are very perceptible in the young larva, being of a colour more brilliant than the other parts of the body. They are shown in the figure like a bundle of strings or cords, extending from the centre of the head to the extremity of the third joint of the body.

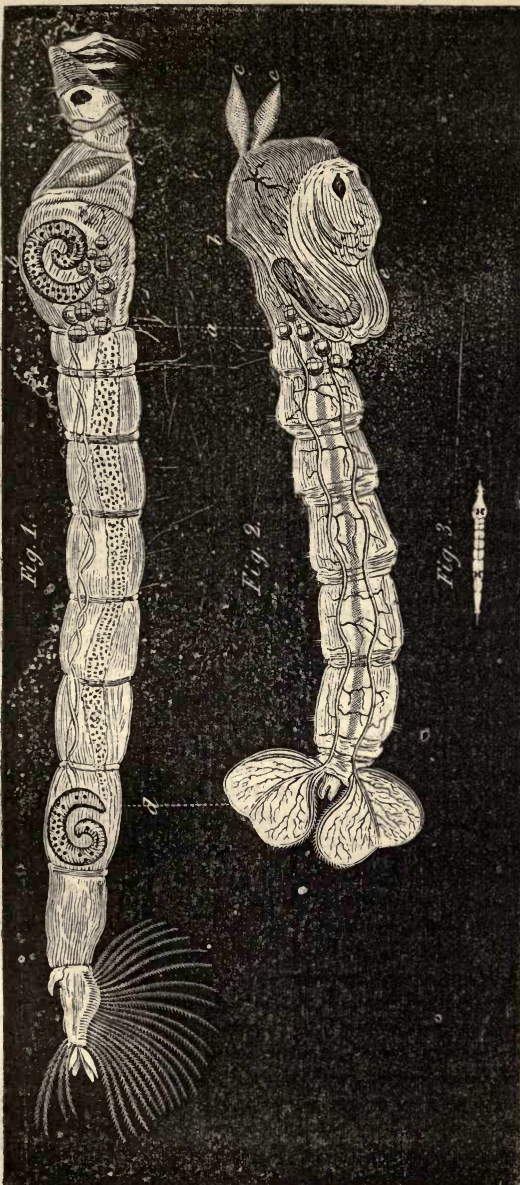
The two large tracheæ, commencing from the head, attain their greatest development about the third joint of the body. They follow the sides of the body to a point near its extremity, where they coalesce and terminate. These air-tubes, in their passage along the body, throw out numerous ramifications, which are shown in the figure. These tracheæ are four in number, two interior and two exterior. The interior ones commence at the ganglion, which terminates at the third joint of the body, and they disappear at the third joint from the tail. In the last joint but one is situated the organ of pulsation.

58. Dr. Goring has also left two very beautiful engravings of the larva and the pupa of the gnat, taken from a specimen of the species called tipula crystallina of De Geer, the chironomus plumicornis of Fabricius, and the corethra plumicornis of Stephens. I have reproduced these beautiful objects from Dr. Goring's engravings, the larva being represented in fig. 1, the pupa in fig. 2, and a plan, or bird's-eye view of the larva, in its natural size, in fig. 3.

The gnat, of which these are the previous forms, is represented in fig. 36, the drawing having been taken while the creature was in the act of laying the cluster of eggs figured on the right side. The short line between the figures gives the real length of the

* Westwood on "Insects," vol. i., p. 95.

STRAW-COLOURED GNAT.



body of the insect. The length of the eggs varies from the 40th to the 50th of an inch.

In the larva (fig. 1) the obvious and curious parts are the kidney-shaped bodies, *b* and *d*, two of which are situated near the

Fig. 36.

head, and the other two in the third division from the lower extremity. The first pair are inclined towards each other, while the others lie in parallel planes, as represented in the plan, or bird's-eye view, drawn of the natural size in fig. 3. Physiologists have not ascertained what may be the functions performed by these singular organs: it is worthy of remark, however, that a similar structure is observable in the tadpole, and figured in Sir Everard Home's Lectures on Comparative Anatomy. The other parts of its structure, which appear equally singular and curious, are a number of globules, *a*, which are situated near the first pair of bodies, *b*. These globules have a slight oscillatory motion in different directions, and, like the reniform bodies, seem to have a metallic lustre, but are not opaque. From the exquisite polish of these globules, they reflect the forms of surrounding objects, as window-bars, &c., which are indicated in the drawing by small squares, resembling the images formed by convex mirrors.

When the larva, as shown of the full size in fig. 3, is examined from above, it exhibits the position and decussation of the various muscles lying along the back, which are observed to cross at the joints, and at points situate midway between them.

The alimentary canal appears to contain some particles of a pinkish coloured matter: but every part of the object, as seen beneath the microscope, is so accurately noted in the drawing, that a more minute description must be deemed superfluous.

If the insect have a sufficient supply of food, it only continues for a few weeks in the larva state, when it rapidly changes to the pupa, shown in the drawing (fig. 2). When it is desirable to

preserve it for the microscope, this change may be retarded by keeping it in clear spring or river water. The former seldom offers sustenance to animalcules, and, therefore, effects this object, which is often very desirable, on account of the scarcity of this species.

The transformation of this animal from the larva to the pupa is one of the most singular and wonderful changes that can be conceived; and, under the microscope, presents to the admirer of nature a most curious and interesting spectacle. Although the whole operation be under the immediate inspection of the observer, yet so complete is the change, that its former organisation can scarcely be recognised in its new state of existence.

If we now compare the different parts of the larva with the pupa, we remark a very striking change in the tail, which, in the previous state of being, was composed of twenty-two beautifully plumed branches, while, in the latter, it is converted into two fine membranous tissues, ramified with numerous vessels. This change appears the more remarkable, as not the slightest resemblance can be discovered between them, nor are the vestiges of the former tail readily found in the water. The partial disappearance of the shell-like or reniform bodies is another curious circumstance. The lower two, it may be conjectured, go to form the new tail; for, if the number of joints be counted from the head, the new tail will be found appended to that joint which was nearest to them in the larva state, as referred to by the dotted line *d*, connecting figs. 1 and 2. The two small horns, *c c*, which form the white-plumed antennæ of this species of gnat, when in its perfect state, are discernible in the larva, folded up under the skin near the head at *c*, in fig. 1. The alimentary canal appears nearly to vanish in the pupa, as in that state there is no necessity for it, the insect then entirely abstaining from food; while, near this canal, the two intertwined vessels, seen in the larva, have now become more distinct, and are supplied with several anastomosing branches.

During the latter part of the day on which the drawing (fig. 2) was taken, the rudiments of the legs of the perfect insect might be seen, folded within that part which appears to be the head of the pupa, and several of the globules had vanished, those remaining longest that were situated near the head. It may be necessary to observe, that the head of the pupa floats just under the surface of the water; and the insect, in this state, is nearly upright in that fluid, while the larva swims with its body in a horizontal position, or rests on its belly or sides, at the bottom of the pond or vessel in which it is kept, the fringed tail being downwards.

The colour of the larva when young is a faint and scarcely perceptible yellow; but as it approaches the change, it assumes a

richer and deeper colouring, and all its internal parts acquire their definite forms and tints, as exhibited in the drawing.

A curious circumstance attends the observation of this insect; so rapid is its locomotion, that it torments the eye while attempting to delineate it, presenting alternately its head and tail to the observer. This it effects by bending itself laterally into a circular form, and suddenly whisking round in the opposite direction to that in which it had just bent itself.

Many species of this genus of insects are, in their perfect state, possessed of a sheathed proboscis, containing instruments with which they are enabled to pierce the skin of men and cattle, injecting at the same time an acrimonious fluid into the wound. The species we are now describing, however, has not been examined minutely enough to determine the form of these organs. It is of a light straw colour, and has two beautiful antennæ, or feelers.

The wings also of this gnat are of a delicate straw colour, and make very beautiful objects when mounted under thin glass in sliders. Some species have wings marginated, and covered with fine scales. These, as well as the feathers on the edges, are good objects for the microscope, and exhibit five or six longitudinal lines on each, which are so strongly marked as to be seen with any kind of light, and do not require superior penetration in the instrument to show them.

These insects generate while hovering in the air, and the female lays her eggs in the water, selecting an unfrequented spot, where she may deposit them free from danger. This is probably the cause why this larva is discovered with so much difficulty; the collector being seldom able to procure it two seasons consecutively in the same place.

59. The method of executing these drawings, practised by Dr. Goring, differed in nothing from that by which an artist makes a portrait, the eye guiding the pencil, and the accuracy of the resemblance depending altogether upon the skill of the artist.

60. Dr. Goring considered that in such cases the great security for precision offered by the camera-lucida, was not available, owing to the constant mobility of the object delineated; this objection, however, is only applicable to living objects, and that admirable instrument is accordingly used to a great extent in the production of microscopic drawings. As we shall describe it in a future Tract, and explain its mode of application to the microscope, it will not be necessary here to give that exposition. It will be sufficient to observe that a practised draughtsman is capable of giving, not only the general outline, but most of the less minute details of a microscopic object, by a

process precisely similar to, and susceptible of, as much accuracy as that by which a drawing is reproduced on tracing paper. It must be observed, however, that in the finishing touches, and the most minute details, the pencil of the draughtsman must after all be guided by his artistic skill. To what extent this is true, is proved by the fact, that two drawings of the same object, viewed in the same microscope, and made with the same camera, by artists of different skill, will be different.

We shall here, as in the former case, present the reader with some examples of microscopic drawings made by the aid of the camera.

61. In fig. 41 is a magnified section of the human skin, cut inwards at right angles to its surface, to the depth of about the sixth of an inch. The following is the succession of organised parts included within that depth:—*a* the sudoriferous gland; *b c* the sudoriferous duct, leading to the surface of the skin; *d* the subcutaneous cellular and adipose tissue; *e* the derma or true skin; *f* the papillæ; *g* mucous tissue or interior epidermis; *h* the epidermis or superficial skin.

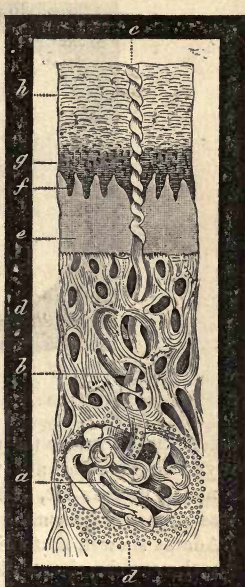


FIG. 41.—MAGNIFIED SECTION OF THE HUMAN SKIN, SHOWING THE PERSPIRATORY GLAND, WITH ITS DUCT, DRAWN WITH A CAMERA BY DR. MANDL.

62. It is now admitted, though the fact was long doubted, that the malady called the itch in the human body, and that called the mange in the horse, are produced by an insect hatched under the cuticle of the skin; the insect which produces the itch, called the *acarus-scabiei*, is represented, highly magnified, in fig. 42. To extract this insect, the operator must, says Mr. Quekett, examine carefully the parts surrounding each pustule, and he will generally find, in the early stage of the disease, a red spot or line communicating with it; this part, and not the pustule, must be probed with a pointed instrument, and the insect, if present, turned out of its lurking-place. The operator must not be disappointed by repeated failures, as in the best marked cases, it is often difficult to detect the haunts of the creature.

63. That the itch is occasioned by such an insect is by no means a modern doctrine. Kirby mentions a Moorish physician, who, in the twelfth century, affirmed that the malady was produced by little mites or lice that creep under the skin of the hands, legs, and feet, producing pustules full of matter; he quotes also "Joubert," another ancient physician, who describes

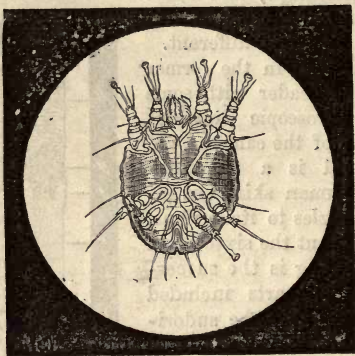


Fig. 42.—VIEW OF THE ITCH INSECT, DRAWN WITH A CAMERA BY DR. MANDL, MAGNIFIED 120 TIMES IN ITS LINEAR, AND THEREFORE 14400 TIMES IN ITS SUPERFICIAL DIMENSIONS.

the itch insects under the name of "sirones," and says they are always concealed beneath the epidermis, under which they creep like moles, gnawing it, and producing a most troublesome itching. It was supposed by some that they were identical with lice; but Dr. Adams showed that this could not be the case, since they live under the cuticle; he speaks of them as living in burrows which they have excavated in the skin, near a lake of water, from which if they be extracted with a needle, and put upon the nail, they show in the sun their red heads and the feet with which they walk; they have been extracted and delineated with the aid of the microscope by many modern observers. The individual delineated in fig. 42, was drawn by my friend Dr. Mandl, well known for his great work on microscopic anatomy.

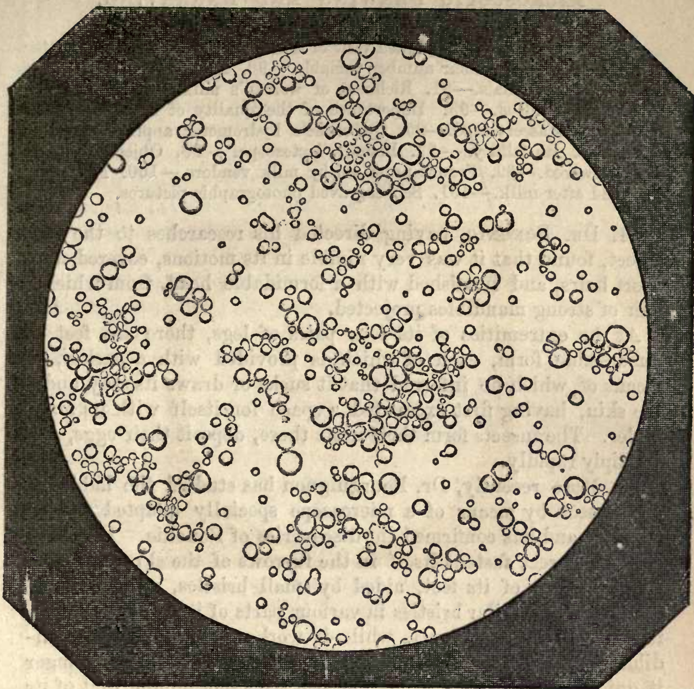


Fig. 40.—THIN DISC OF COW'S MILK, THE 120TH OF AN INCH IN DIAMETER, MAGNIFIED 400 TIMES IN ITS LINEAR, AND 160000 TIMES IN ITS SUPERFICIAL DIMENSIONS.

MICROSCOPIC DRAWING & ENGRAVING.

CHAPTER IV.

64. Structure of the itch insect.—65. Its habits.—66. The mange insect. —67. Its form and structure.—68. Defects incidental to drawing with the camera.—69. Microscopic photographs.—70. Microscopic daguerreotypes by Messrs. Donné and Foucault.—71. Description of the blood.—72. Red and white corpuscles.—73. Daguerreotype of a drop of blood magnified.—74. Magnitude of the corpuscles.—75. Cause of the redness of blood.—76. Corpuscles of inferior animals. —77. White globules.—78. White grains.—79. White globules converted into red corpuscles. — 80. Red corpuscles dissolved. — 81. Circulation of the blood.—82. Method of showing it in the tongue of a frog.—83. The arteries distinguishable from the veins.—84. The vascular system of the tongue.—85. Mucous glands.—86. Milk ; its

constitution.—87. Magnified view of a drop of milk.—88. The butter globules.—89. Their number variable.—90. Analysis of the milk of different animals.—91. Richness of woman's milk.—92. Analogy of milk to blood.—93. Importance of the quality of milk.—94. Its richness ascertained.—95. Quévenne's hydrometer applied to milk. —96. Its fallacy. — 97. Donné's lactoscope. — 98. Objections to it answered.—99. Frauds practised by milk vendors.—100. Fore-milk and after-milk.—101. Self-engraved photographic pictures.

64. Dr. Bononio, having directed his researches to the itch insect, found that it was very nimble in its motions, covered with short hairs, and furnished with a formidable head, from which a pair of strong mandibles projected.

At the extremities of its four pairs of legs, there are feet of remarkable form, each of which is provided with a sucker, by means of which he inferred that it sucks or draws its way under the skin, having first excavated a space for itself with its mandibles. The insects form their nests there, deposit their eggs, and multiply rapidly.

65. More recently, Dr. Bourguignon has studied the habits of this insect by means of a microscope specially adapted to the purpose, and has confirmed the discoveries of Bononio. He found that the insect fastens itself in the furrows of the skin by means of the suckers of its feet, aided by small bristles, being likewise covered with similar bristles in various parts of its body, by which it fixes itself more firmly, while it works its way with its mandibles; it is not furnished with eyes, but in a moment of danger it quickly draws in its head and feet, this motion and that of its gait resembling those of a tortoise. It usually lays sixteen eggs, which it deposits, ranged in pairs, in the furrows under the skin, where they are hatched in about ten days.*

66. The insect which produces or accompanies the mange in horses, and which is called the *acarus-exulcerans*, is represented in fig. 37, p. 49, magnified in its linear dimensions one hundred and fifty times.

67. This animalcule is larger and more easily obtained than the former; it is found under the whitish scales which are detached from the skin of the horse, and if several individuals be taken, they will be found to be in different states of development, having four pair of legs when full grown; the two foremost pairs are terminated in a strong and sharp claw, and their general form is like that of the legs of a flea, consisting of five joints or segments.

The head consists of nothing but a mouth, in which the organs of mastication are seen, consisting of a pair of very fine and sharp

* Bourguignon, quoted by "Hogg" on the Microscope, p. 318.

mandibles terminated by two teeth, the form of the entire organ being that of a pincers. The skin, which is of a tough leathery texture, is elegantly marked by sinuous and parallel tracings, bearing some resemblance to engine-turning. Wrinkles are in some places seen upon it, as if it were divided into separate segments, united edge to edge, like the bones composing the human skull; upon the legs, the skin is finely granulated and not striated, as upon the body; several long hairs issuing from the legs are seen in the figure.

68. Although the general fidelity of microscopic drawings made with a camera may be relied upon, yet, as has been already observed, the more minute details are executed by the artist in the same manner as that in which a portrait-painter produces his effects, and in whatever degree the artistic skill of the draughtsman may be manifested in such parts of the drawing, the rigorous fidelity demanded by science, even in the minutest arts, cannot be claimed for them.

69. Under these circumstances, other means, ensuring more rigorous accuracy, and rendering the drawing independent altogether of those impulses which imagination and taste never fail to impart to the pencil even of the most conscientious artist, have been eagerly sought by naturalists, and have been happily supplied by photography. The magnified image of the object under examination, produced by a solar microscope, is received upon a prepared daguerreotype-plate, or a leaf of photographic paper, and there the optical image delineates itself with the most unerring fidelity and rigorous accuracy.

70. This felicitous application of the photographic art, to the promotion of natural science, after some experimental essays, more or less successful, was first carried out, so as to be available for the practical purposes of science, by Dr. Donné, assisted by M. Leon Foucault, in 1845. In that year Dr. Donné published an atlas to illustrate his course on microscopic anatomy and physiology, which had appeared in the previous year, consisting of twenty plates, on each of which were four microscopic engravings, made from daguerreotype plates which had been produced in the manner above described. I avail myself gladly of the kind permission of the authors of this work, and of Mr. Baillière, its publisher, to reproduce four of these engravings upon the scale on which they are given by the authors.

71. The blood of animals is not, as it seems at first view to be, a homogeneous liquid holding in complete solution certain substances, and destitute of all solid and concrete matter; if it were so, we could not follow its course through the vessels in which it moves, as we do so easily and distinctly with the microscope.

The motion of an homogeneous liquid in tubes completely filled with it could not be made sensible to the sight; but on the other hand, that of a liquid containing solid particles suspended in it, continually entering into collision with and displacing each other, would be perfectly visible.

The blood therefore contains certain solid particles floating in and circulating with it, to which moreover are due several of its most important properties; these particles exist in countless numbers, and of minuteness so extreme, that a single drop of blood, no larger than might be suspended from the point of a needle, contains myriads of them. Until recently, observers recognised only one species of the corpuscles, such being the only ones perceivable by the ordinary methods of observation, and being incomparably more numerous than the others, which, besides being more rare, are generally hidden by the former, which completely fill the field of the microscope.

72. These sanguineous corpuscles are distinguished by regular and constant forms, by a complex composition and a determinate structure. They possess a real organisation, and pass through a regular succession of phases, having a beginning, a development, and an end.

They consist of three species: first, red corpuscles; secondly, white globules; and thirdly, white granular particles, much smaller, to which observers have applied the name "globulines."

73. Nothing can be more simple or more facile than the method of observing the first class of these corpuscles. Take a sharp needle and prick with it slightly the end of the finger, so as to draw the smallest drop of blood; having previously rendered a small slip of glass perfectly clean and dry, touch it with the blood, a small portion of which will adhere to it, and upon this lay a thin film of glass, such as are prepared by the opticians for microscopic use, so as to flatten between the two glasses the small drop of blood. Let the glass thus carrying the blood be placed under a microscope having a magnifying power of about 400; a multitude of the red corpuscles will then be immediately visible, distributed irregularly over the field of view of the instrument.

Fig. 38, p. 81, has been reproduced from one of Dr. Donné's engravings; it represents a thin disc of human blood, having a diameter equal to the 120th part of an English inch, included between the two glasses.

The red corpuscles alone are here visible; their form is that of flat discs a little concave in the middle, swelling upwards towards the edges, which are slightly rounded. Some of them, such as *a a a*, are presented with their flat sides to the line of sight, so as to show very distinctly their form; others, such as *b b*, are

seen edgeways, and others at all degrees of obliquity; some are scattered separately, but others are grouped together in piles, with their edges presented to the eye, having the appearance of rouleaux of coin lying on their sides on a table, the faces of the coins being more or less inclined to the surface of the table.

The flat disc-shape form of the corpuscles was not recognised by the earlier observers, who took them to be red spherules. The cause of this error was not any defect of their observation, but arose from their having previously washed the blood with water, being ignorant that the immediate effect of the contact of water with human blood is to change the form of the flat corpuscles into that of little globes.

74. The magnitude of these corpuscles, since the recent improvements of the microscope, has been very exactly measured. Their diameters are found to vary from the 3125th to the 3000th of an inch: this small variation being due to their different states of development, as will be presently explained.

75. The blood consists of a transparent, limpid, and colourless fluid, in which the solid particles already mentioned float, and the redness of which arises altogether from the colour of the corpuscles here described. A person, who may observe for the first time these corpuscles with the microscope, is generally surprised and disappointed to find that they are not red, but rather of a yellowish colour, having a very faint reddish tint. This circumstance, however, is an optical effect of a very general class, which has been explained more than once in our Tracts. When any coloured medium is submitted to the eye, the depth of its tint will always be diminished with the thickness of the medium, which may be reduced to such a degree of tenuity as to render its peculiar colour altogether imperceptible. We mentioned formerly, as an example of this, the case of coloured wine, such as sherry, viewed through a tapering Champagne glass. At the upper part, where the eye looks through a greater thickness of the liquid, the peculiar gold colour is strongly pronounced; but in going downwards to the point of the cone, the colour becomes paler and paler, and at the very point is scarcely perceptible. It is the same with the red corpuscles of the blood. When they are seen singly through their very minute thickness, they appear of the faintest reddish yellow; seen in rouleaux edgeways, they are redder; but it is only when amassed together, in a stratum of blood of some thickness, that they impart to the liquid the red colour so characteristic of the blood.

76. The disc-shaped form which thus characterises human blood, is common to all species of animals which suckle their young, with the single exception, so far as is known at present,

of the camel species. It appears, from some recent observations of Dr. Mandl, that the blood of this species presents an anomalous exception, the red corpuscles being elliptical in their form, but still flat and concave at their sides.

In comparing the red corpuscles of the blood of different species of mammalia, or suckling animals, one with another, they are found to vary in their diameters, being greater or less in different species, but the variation in each species being confined within narrow limits, as in man.

The corpuscles of the blood of birds, fishes, and reptiles, are all like those of the exceptional case of the camel, oval discs of various magnitudes, somewhat concave in their centres, like the blood of mammalia.

77. The discovery of the white globules is entirely due to recent observers, and particularly to Professor Müller, Dr. Mandl, and Dr. Donné.

The white globules have nothing in common with the red corpuscles, either as to colour, form, or composition. Unlike the latter, they are spherical, their contour is slightly fringed, and not well defined like that of the red corpuscles; their surface is granulated, and their diameter is a little greater, varying from the 2500th to the 3000th of an inch. They appear to consist of a thin vesicle, or envelope, the interior of which is filled with solid granulated matter, consisting usually of three or four grains, while the red corpuscles are filled with an homogeneous and semi-fluid matter in the case of mammalia, and a single solid kernel in the case of other vertebrated animals.

The white globules also have chemical properties totally different from those of the red corpuscles.

78. In fine, the third class of solid particles which float in the blood cannot be properly denominated globules, being only very minute granulations, which are continually supplied by the chyle to the sanguineous fluid; they appear in the microscope as minute roundish grains, isolated, or irregularly agglomerated, and having a diameter not exceeding the 8000th of an inch: they have, however, a physiological importance of the first order, since they are the primary elements of the blood, and therefore of all the other organised parts of the body.

79. It appears to follow from the observations, researches, experiments, and reasoning of Dr. Donné, that these granular particles form themselves into the white globules by grouping themselves together, and investing themselves with an albuminous envelope. By a subsequent process, the white globules are converted gradually into the red corpuscles, the place where this change is produced being supposed by Dr. Donné to be the spleen.

80. In fine, the red corpuscles, after having been fully developed in the circulation, are dissolved, and being converted into the fibrinous fluid, pass into the other parts of the organisation, so as to form the different organs of the system.

81. Next to the constitution of the blood, no subject connected with it is more interesting and important than its circulation, and we know no spectacle presented by any of the scientific artifices, by which the secret operations of nature are disclosed to our view, which excites more astonishment and admiration than the circulation of the blood, as rendered visible with the microscope.

82. Let any one imagine an animal organ, full of every variety of blood-vessels of the most complex structure, into the composition of which enter every form of organ: arteries, veins, capillaries, muscles, nerves, glands, and membranes: representing in short a microcosm of the whole animal organisation; and let us suppose this brought within the field of the microscope, so as to display, before the wondering view of the observer, all the complicated motions and operations of which it is the theatre. Such a spectacle is presented by the tongue of the frog, an object first submitted to this species of experiment by Dr. Donné, at the suggestion of a young Englishman, a Mr., since Dr., Waller, who was in attendance upon his course. The method of accomplishing this, with some modifications, as described in the Physiological Journal, is as follows:—"A piece of cork, from two to three inches in breadth, and six to eight inches in length, is to be procured, in which is to be bored, a hole of about half an inch in diameter midway between the sides, and about an inch and a half to two inches from one of its ends. In this part the piece of cork should be of double thickness, which is effected by joining, by means of marine glue, a small piece of cork upon the first piece. Upon this is laid the frog, previously enveloped in a linen band, or fixed to the cork by pins thrust through the four extremities, so as to prevent any great movements of its body or its feet; it is placed upon the back, the end of the nose abutting on the border of the hole. The tongue, the free end of which is directed backwards, is then to be drawn out of the mouth gently with a forceps, and slightly stretched and elongated until it reaches a little beyond the opposite edge of the hole, where it is to be fastened by two pins; the sides are to be fastened over the hole in a similar way. In this state, the tongue presents the appearance of a semi-transparent membrane, which permits us to see through its substance; and when placed between the light and the object-glass of the microscope, offers one of the most beautiful and marvellous spectacles which can possibly be witnessed. It will be found most

convenient to view it, first, with a simple magnifying-glass, having a power of 15 to 20, so as to obtain a general view of the vessels and of the circulation; even with this small power the observer will be filled with astonishment at the magnificence of the spectacle, especially if a strong light is thrown upon the lower side of the tongue. To imagine a geographical map to become suddenly animated, by their proper motions being imparted to all the rivers delineated upon it, with their tributaries and affluents, from their fountains to their embouchures, would afford a most imperfect idea of this object, in which is rendered plainly visible, not only the motion of the blood through the great arterial trunks, and thence through all their branches and ramifications to the capillaries, but also its complicated vorticular motions in the glands, its return through the smaller ramifications of the veins to the larger trunk veins, and its departure thence *en route* for the heart. Such is the astonishing spectacle, circumscribed within a circle having the diameter of the 120th of an inch, magnified, however, 400 times in its linear, and therefore 160000 times in its superficial dimensions, which has been daguerreotyped by Messrs. Donné and Foucault, and which is reproduced on the same scale in fig. 39, p. 65.

83. The arteries are distinguishable from the veins very readily, by observing the direction in which the blood flows, its velocity, and their comparative calibre. In the arteries the blood flows from the trunk to the branches, its course is marked by the arrows in fig. 39, where *t* is a trunk-artery entering near the lowest point of the field of view; the arrows show the course of the blood passing into the principal branches, 1, 2, and 3, from which it flows into all the smaller arterial ramifications. The course of the blood in the veins, on the contrary, is from the branches to the trunk, from whence it finds its way back to the heart. The arteries, moreover, are of less calibre than the veins, and consequently the blood flows in them with greater velocity. The greater arteries are accompanied by a greyish flexible cord, which can be perceived, but not without some attention; it passes along the sides of the artery: this cord is only a nerve.

As the ramifications of the arteries are multiplied they are diminished in calibre, and merge at length in the capillaries, from which they are scarcely distinguishable, the latter being equally indistinguishable from the smaller veins. As these conduits of the blood diminish in diameter, the red corpuscles at length so completely fill them, that they can only move in them one by one, and they can be thus seen following one another at perceptible intervals. If the microscope be directed to that part of the edge of the tongue, which is within the limits of the hole made in the

cork, the blood can be traced in its course to the extreme arteries, and thence from the smaller to the larger veins on its return to the heart.

84. The vascular system of the tongue appears traced upon a greyish semi-transparent brown, on which a multitude of fine fibres, *v v*, are seen extended in different directions; these existing at different depths within the thickness of the tongue, appear superposed and interlaced; these fibres belong to the muscle of the organ, and their characteristic action is rendered evident in the microscope, by their alternate contraction and extension. A number of greyish spots, somewhat round in their outline and a little more opaque than the neighbouring parts, appear scattered through the tongue; these spots belong to the mucous-membrane, and are in fact parts of the glands in which saliva is secreted. They are the theatres of a surprisingly complicated and active blood-motion. The sanguine fluid enters them at one side, generally by a single small artery, rarely by two, and following the course of this artery, it pursues a nodulated path, resembling the form of a bow of ribbon, or the figure 8, and issues from them at a point opposite to that it entered. The organ of which we speak, says Dr. Donné, having a certain thickness, we cannot always see at once the entrance and departure of the blood, the point of its departure being often in a plane inferior or superior to that of its entrance, and the two points not being, therefore, at the same time in focus. But in any case, nothing can be more curious or more profoundly interesting than the vortices of rapid circulation, thus exhibited, in a space so circumscribed and within the limits of an organ, which is evidently one of secretion.

85. These greyish spots in short, in which the circulation proves to be so active, are nothing but the mucous-follicles of the tongue, the little glands in which is secreted the viscous humour which coats in such abundance the tongue of the frog, and we accordingly find that if it be wiped off, it will be almost immediately reproduced.

86. The milk of mammalia being the first nourishment taken by their young, and their only nourishment until a certain epoch of their growth, it might naturally be expected that that fluid would have a close analogy to the blood. The examination of milk accordingly, whether with the microscope or by means of chemical analysis, proves such an anticipation to be well-founded. If a small drop of milk be laid upon a clean slip of glass, and covered by a thin film of glass, so that a thin stratum of the fluid shall be included between them, it is found on submitting it to the microscope, in the same manner as has already been described

in the case of the blood, that very similar appearances are presented. A multitude of minute pearly spherules with the most perfect outline, reflecting light brilliantly from their centre and varying in magnitude from the 12500th to the 3000th part of an inch in diameter, and even larger still, are seen floating in the fluid.

The general magnitude and number of these globules vary much, not only in the case of one species of animal compared with another, but with different individuals of the same species, and even with the same individual under different circumstances.

87. In fig. 40, p. 97, we have given the appearance presented by a thin disc, the 120th of an inch in diameter, of common cow's milk magnified 400 times in its linear, and therefore 160000 times in its superficial dimensions, engraved from a daguerreotype by MM. Donné and Foucault.

88. It appears from the researches of physiologists on this subject that the pearl-like globules, which thus float in such multitudes in milk are the constituents out of which butter is formed. The serous fluid in which they float is composed of the constituent out of which cheese is formed, combined with another substance called sugar-of-milk, and water, the last constituting from 80 to 90 per cent. of the whole, so that, in fine, milk in general may be regarded as water holding in solution the substances called sugar-of-milk and caseine, the name given to the cheesy principle, with the globules of butter already described floating in it.

89. The proportion in which these constituents enter into the composition of milk varies, the richness always depending on the proportion of globules of butter contained in it.

90. The following is an analysis of the milk of the woman, the cow, the goat, and the ass, according to Meggenhofen, Van-Stiptrian, Liuscius, Bonpt, and Péligot:—

	Woman.	Cow.	Goat.	Ass.
Butter	8·97	2·68	4·56	1·29
Sugar of Milk . . .	1·20	5·68	9·12	6·29
Cheesy matter . . .	1·93	8·95	4·38	1·95
Water	87·90	82·69	81·94	90·47
	100·00	100·00	100·00	100·00

91. From this and similar analyses it appears that woman's milk is by far the richest of the mammalia, containing generally little short of 10 per cent. of butter, while the milk of other species contains no more than from 1 to 4 per cent. of that principle.

It must, however, be observed that these are average proportions,

and that the richness of the milk differs considerably in different individuals. It is found that in all cases the milk is sufficiently rich in the cheesy principle, the constituent in which it fails being the butter, which is the most important in respect to nutriment.

The butter globules of woman's milk, though much greater in quantity, as appears above, than those in the milk of inferior animals, appear from the observations of Dr. Donné to be smaller in magnitude. We have given in fig. 43, the appearance

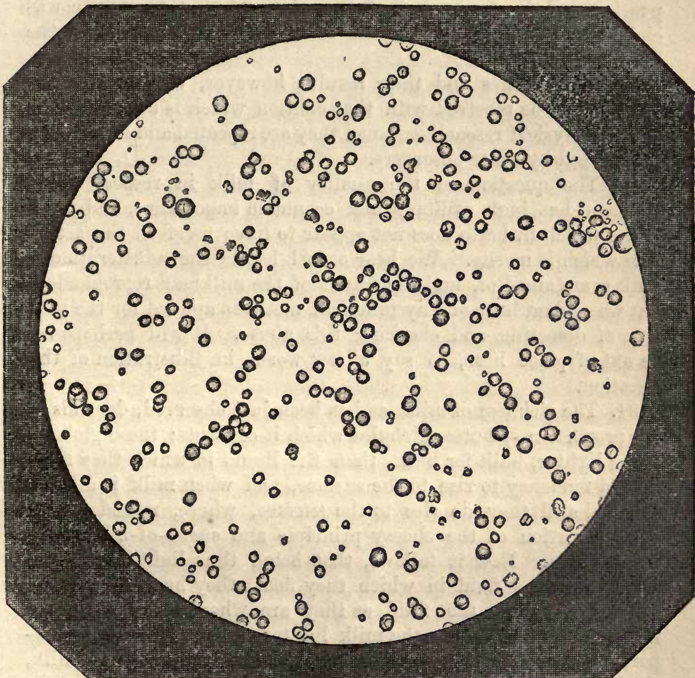


Fig. 43.—THIN DISC OF WOMAN'S MILK, THE 120TH OF AN INCH IN DIAMETER, MAGNIFIED 400 TIMES IN ITS LINEAR, AND 160000 TIMES IN ITS SUPERFICIAL DIMENSIONS.

of a disc of ordinary woman's milk, magnified similarly to fig. 40. The difference between the magnitude of the globules is apparent.

92. The analogy of milk to blood manifested in a manner so striking by the microscope, was still farther investigated in a series of highly interesting experiments made by Dr. Donné.

That eminent physiologist transfused milk into the blood vessels of various animals, with all the precautions necessary to prevent the admission of air. It was found generally that the vital functions of the animal, were neither interrupted nor disturbed; the milk mingled with the blood and circulated with it through the system, its presence being detected in all the vessels. But the most interesting and important result of these researches, was, that the butter globules of the milk were found to assimilate themselves to, and play the same part with, the white globules of the blood, and like them were gradually converted into red corpuscles, and it appeared that the place where this change was elaborated was, as in the case of the white corpuscles of the blood, the spleen.

These researches and their results, however, being recent and novel, must be received with that caution which is always necessary in physical researches, until they are repeated and like results reproduced by other observers.

93. The question of the quality of milk in respect to its richness, has high sanitary and economic importance, and yet it is one which hitherto does not appear to have received the attention which it merits. We hear on all hands the adulteration of milk complained of, and the frauds of the milkman reprehended; but we seldom hear of any practical methods applied for the purpose of detecting and checking this abuse. It will perhaps not be out of place here, to say a few words in illustration of this question.

94. The richness of milk, as has been just observed, depends on the proportion of butter globules which it contains; these globules being lighter, bulk for bulk, than the liquid in which they float, have a tendency to rise to the surface, and when milk is allowed to stand still they do rise to the surface, where, mixed with a certain portion of the cheesy principle and sugar-of-milk, they form cream. Now it follows, that being thus lighter, bulk for bulk. than the fluid in which they float, they have a tendency, when mixed with that fluid, as they are when the milk is in its natural state, to render the milk lighter, and the larger the proportion is in which these butter globules are mixed with the milk, the lighter will be the milk. It was therefore inferred, that the lightness of the milk might be taken as a test of its richness, and M. Quévenne invented a species of hydrometer, which he proposed to apply to test the richness of milk, in the same manner as the ordinary hydrometer is applied to test the strength of spirits. But the indications of this instrument, ingenious as it is, are fallacious.

95. Let us suppose that the fraudulent milkman allowing the

milk he proposes to sell, to stand until the richer portion forms a creamy stratum at its surface, then skims off this stratum which he sells at a high price, as cream. The remainder and impoverished portion of the milk is then undoubtedly heavier than before it was deprived of the cream, and its poverty would be detected by Quévenne's hydrometer: but the crafty milkman, aware of this, has the adroitness, not only to correct the too great weight of the fluid, but to do so to his own increased profit. He knows that the addition of water will diminish the specific gravity of his skimmed milk, and he accordingly mixes with it just so much of that cheap liquid as will reduce its weight to that of milk of the proper richness.

96. This manœuvre is attended also with another deceptive effect; it is found that the mixture of water with milk facilitates the disengagement of cream, and expedites its collection at the surface. Whatever creamy particles, therefore, may remain in the milk thus impoverished and adulterated, will rise quickly to the surface, and collecting there, will deceive the consumer, producing the impression that the milk on which cream so quickly collects, must necessarily be rich.

The great importance of discovering such an easy and practicable test of the quality of an element so important to the sanitary condition of the people, as milk, ought, one should have supposed, to stimulate scientific men to such an invention. The frauds practised so extensively by the vendors of milk on great public establishments, such as hospitals and schools, are notorious. An eminent medical practitioner says, that in conversing with one of the great milk contractors of the public establishments in Paris, during a season in which forage had risen to a very high price, the milkman observed frankly, and with a smile, "in common seasons, we do put a little water to the milk, but at present we are obliged to put milk to the water."

97. Dr. Donné has invented an instrument to ascertain the richness of milk, which he calls a *lactoscope*, which was presented to the Academy of Sciences, and favourably reported upon by a committee consisting of MM. Thénard, Chevreul, Boussingault, Regnault et Séguier, who experimented with it and verified its results. This instrument is based upon the fact, that while the butter globules, which float in milk, are opaque, the liquid which surrounds them is nearly transparent. It follows from this, that the transparency of milk will diminish as its richness increases, and *vice versâ*.

The lactoscope consists of two plates of glass, set parallel to each other, so as to form a cell in the end of a tube, like an opera-glass, the cell being at the wide end of the tube. A screw-

adjustment is provided, by which the distance between the plates of glass may be varied within certain limits, so that by turning the screw in one way, the plates may be brought into absolute contact, and by turning it the other way, they may be separated by any desired interval. Over this cell, is provided a small cup, with a hole in its bottom, by means of which the cell may be filled with milk. Let us now suppose this cup to be filled with the milk to be tested, the screw having been previously turned until the plates of glass composing the cell are in contact. The milk in that case, will not pass between them, but will remain in the cup. Let the observer, applying his eye to the small end of the instrument, look through the cell at the flame of a candle, placed at about three feet distance from it, and let him at the same time slowly turn the screw, so as to let the milk flow into the cell; at first the candle will be seen dimly through the milk, but when the plates have been separated by the screw to a certain distance, the flame will be no longer visible, being intercepted by the multitude of butter globules in the milk.

Now it will be found, as may be expected from what has been explained, that the poorer the milk is, the greater will be the distance to which the glasses must be separated in order to intercept the flame, and the richer it is, on the other hand, the less will be the distance which will suffice to produce that effect.

These instruments are made and sold by the Paris opticians.

98. It may be objected that the certainty of this instrument depends upon the fact that the milk is impoverished either by skimming it or by mixing it with water, but that if it be adulterated by any substance which will promote its opacity, the indications of the instrument must fail. The answer to this objection is, that such a mode of adulteration is impracticable; the substance used for such a fraudulent purpose must in the first place be one, which, when mixed with the milk, will not sensibly alter its conspicuous and well-known properties, such as its colour, taste, odour, and general consistency. It must, moreover, be soluble in the milk, and not merely mixed with it, since if so, it would either sink to the bottom, forming a sediment, or rise to the top, as oil would in water, and in either case, would be immediately detected. It must also be such as will not be disengaged by heat, and thereby be betrayed in boiling the milk: in fine, it must obviously be a substance cheaper than milk, and the process of combination must be so simple as to be inexpensive and to admit of a certain secrecy; now it is quite apparent, that there is one substance only which will fulfil all these conditions, and that substance is water.

99. The frauds practised by the vendors of milk do not always

consist in adulteration; we have already mentioned the case of skimming the milk, and selling the richer and poorer portions at different prices; this cannot be characterised as fraud, so long as the difference of quality is admitted, but yet it has the effect of fraud upon the consumer of the skimmed portion, for the milk he obtains is precisely the same in quality as he would obtain if the milkman instead of skimming the milk had left it in its natural state, but watered it, so as to reduce it to the poverty of skimmed milk.

100. There is another expedient, commonly enough practised, which is attended with similar effects, when the milk is allowed to accumulate in the breasts or dugs of the animal until they become filled and distended, the first portion drawn from them will be poor, and the milk will become richer and richer until the vessels are emptied. This physiological fact is quite familiar to dairymen, who divide the milking of the cow into two parts, the fore-milk and the after-milk; the latter being sometimes called *strippings*. Now this richer portion of the milk is often reserved for cream, the fore-milk only being sold to the consumer. In accordance with the same principles it will be easily understood, that the more frequently the animal is milked, the more uniformly rich will be the fluid.

All the circumstances here explained, and the tests provided, to ascertain the quality of the milk of inferior animals, are equally applicable to human milk. Wet-nurses differ one from another evidently enough in the abundance of their milk, and this is a point which, accordingly, is never overlooked in the selection of nurses. The quality of the milk, however, being much less obvious, is rarely attended to. Yet it is even more important than the mere question of quantity. The physical researches of some of the French physiologists have shown that cases frequently occur in which there is a superabundance of milk; and where, though the woman presents the aspect of health and vigour, the milk is poor in butter, the globules being small either in magnitude or number, or both; they are sometimes observed to be ill-formed, to float in a liquid of little density, and sometimes to be mixed with corpuscles of mucus and of a granular substance. These are characters incompatible with the healthiness of the milk, yet they are such as can only be detected by the microscope. Nevertheless, it is rare indeed that the medical practitioner ever thinks of instituting such inquiries, much less of resorting to the microscope or any other lactoscopic test.

101. We have now indicated, so far as we are informed, all the methods by which the representations of microscopic objects are obtained, and of these that which gives the strongest guarantee of

accuracy and fidelity is the photographic method. It must, however, be observed, that even in this method, as it was practised in the production of the Microscopic Atlas of Messrs. Donné and Foucault, there is still a possible source of inaccuracy remaining, the engraver having to reproduce the photographic picture upon his plate, and for the fidelity of this process, there is no other guarantee than the general accuracy of the engraver's art.

Measures are, however, now being taken, with a fair prospect of success, by which an optical picture being projected upon a plate, will engrave itself—an approach to this has indeed been made; the photographic picture being projected upon a surface of wood, properly prepared and being there delineated by its own light, as it would be on a daguerreotype plate. The engraver after this has nothing to do but to follow the lines of the picture with his graving tool.

Attempts, however, are being made to cause the light itself to engrave the plate, and I have seen microscopic pictures of the blood corpuscles thus self engraved, which, if not completely satisfactory as works of art, have been sufficient to impress me with the conviction, that we are not far from the attainment of a measure of such high scientific importance as that of making natural objects engrave themselves.

LONDON, *January*, 1856.

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